

# Other Particle Searches

OMITTED FROM SUMMARY TABLE

NODE=S015

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## OTHER PARTICLE SEARCHES

Revised February 2018 by K. Hikasa (Tohoku University).

We collect here those searches which do not appear in any other search categories. These are listed in the following order:

- Concentration of stable particles in matter
- General new physics searches
- Limits on jet-jet resonance in hadron collisions
- Limits on neutral particle production at accelerators
- Limits on charged particles in  $e^+e^-$  collisions
- Limits on charged particles in hadron reactions
- Limits on charged particles in cosmic rays
- Searches for quantum black hole production

Note that searches appear in separate sections elsewhere for Higgs bosons (and technipions), other heavy bosons (including  $W_R$ ,  $W'$ ,  $Z'$ , leptoquarks, axiguons), axions (including pseudo-Goldstone bosons, Majorons, familons), WIMPs, heavy leptons, heavy neutrinos, free quarks, monopoles, supersymmetric particles, and compositeness.

We no longer list for limits on tachyons and centauros. See our 1994 edition for these limits.

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### CONCENTRATION OF STABLE PARTICLES IN MATTER

NODE=S015405

#### Concentration of Heavy (Charge +1) Stable Particles in Matter

NODE=S015CON  
NODE=S015CON

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
• • • We do not use the following data for averages, fits, limits, etc. • • •				
$<4 \times 10^{-17}$	95	<sup>1</sup> YAMAGATA	93 SPEC	Deep sea water, $M=5-1600m_p$
$<6 \times 10^{-15}$	95	<sup>2</sup> VERKERK	92 SPEC	Water, $M=10^5$ to $3 \times 10^7$ GeV
$<7 \times 10^{-15}$	95	<sup>2</sup> VERKERK	92 SPEC	Water, $M=10^4$ , $6 \times 10^7$ GeV
$<9 \times 10^{-15}$	95	<sup>2</sup> VERKERK	92 SPEC	Water, $M=10^8$ GeV
$<3 \times 10^{-23}$	90	<sup>3</sup> HEMMICK	90 SPEC	Water, $M=1000m_p$
$<2 \times 10^{-21}$	90	<sup>3</sup> HEMMICK	90 SPEC	Water, $M=5000m_p$
$<3 \times 10^{-20}$	90	<sup>3</sup> HEMMICK	90 SPEC	Water, $M=10000m_p$
$<1. \times 10^{-29}$		SMITH	82B SPEC	Water, $M=30-400m_p$
$<2. \times 10^{-28}$		SMITH	82B SPEC	Water, $M=12-1000m_p$
$<1. \times 10^{-14}$		SMITH	82B SPEC	Water, $M > 1000 m_p$
$<(0.2-1.) \times 10^{-21}$		SMITH	79 SPEC	Water, $M=6-350 m_p$

OCCUR=2

OCCUR=3

OCCUR=2

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OCCUR=3

<sup>1</sup>YAMAGATA 93 used deep sea water at 4000 m since the concentration is enhanced in deep sea due to gravity.

NODE=S015CON;LINKAGE=C

<sup>2</sup>VERKERK 92 looked for heavy isotopes in sea water and put a bound on concentration of stable charged massive particle in sea water. The above bound can be translated into into a bound on charged dark matter particle ( $5 \times 10^6$  GeV), assuming the local density,  $\rho=0.3$  GeV/cm<sup>3</sup>, and the mean velocity  $\langle v \rangle=300$  km/s.

NODE=S015CON;LINKAGE=A

<sup>3</sup>See HEMMICK 90 Fig. 7 for other masses 100–10000  $m_p$ .

NODE=S015CON;LINKAGE=B

**Concentration of Heavy Stable Particles Bound to Nuclei**

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
$<1.2 \times 10^{-11}$	95	1 JAVORSEK	01 SPEC	Au, $M= 3 \text{ GeV}$
$<6.9 \times 10^{-10}$	95	1 JAVORSEK	01 SPEC	Au, $M= 144 \text{ GeV}$
$<1 \times 10^{-11}$	95	2 JAVORSEK	01B SPEC	Au, $M= 188 \text{ GeV}$
$<1 \times 10^{-8}$	95	2 JAVORSEK	01B SPEC	Au, $M= 1669 \text{ GeV}$
$<6 \times 10^{-9}$	95	2 JAVORSEK	01B SPEC	Fe, $M= 188 \text{ GeV}$
$<1 \times 10^{-8}$	95	2 JAVORSEK	01B SPEC	Fe, $M= 647 \text{ GeV}$
$<4 \times 10^{-20}$	90	3 HEMMICK	90 SPEC	C, $M = 100m_p$
$<8 \times 10^{-20}$	90	3 HEMMICK	90 SPEC	C, $M = 1000m_p$
$<2 \times 10^{-16}$	90	3 HEMMICK	90 SPEC	C, $M = 10000m_p$
$<6 \times 10^{-13}$	90	3 HEMMICK	90 SPEC	Li, $M = 1000m_p$
$<1 \times 10^{-11}$	90	3 HEMMICK	90 SPEC	Be, $M = 1000m_p$
$<6 \times 10^{-14}$	90	3 HEMMICK	90 SPEC	B, $M = 1000m_p$
$<4 \times 10^{-17}$	90	3 HEMMICK	90 SPEC	O, $M = 1000m_p$
$<4 \times 10^{-15}$	90	3 HEMMICK	90 SPEC	F, $M = 1000m_p$
$< 1.5 \times 10^{-13}/\text{nucleon}$	68	4 NORMAN	89 SPEC	$206\text{Pb}X^-$
$< 1.2 \times 10^{-12}/\text{nucleon}$	68	4 NORMAN	87 SPEC	$56,58\text{Fe}X^-$

NODE=S015CNM  
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OCCUR=2

OCCUR=2

OCCUR=3

OCCUR=4

OCCUR=2

OCCUR=3

OCCUR=4

OCCUR=5

OCCUR=6

OCCUR=7

OCCUR=8

<sup>1</sup> JAVORSEK 01 search for (neutral) SIMPs (strongly interacting massive particles) bound to Au nuclei. Here  $M$  is the effective SIMP mass.

<sup>2</sup> JAVORSEK 01B search for (neutral) SIMPs (strongly interacting massive particles) bound to Au and Fe nuclei from various origins with exposures on the earth's surface, in a satellite, heavy ion collisions, etc. Here  $M$  is the mass of the anomalous nucleus. See also JAVORSEK 02.

<sup>3</sup> See HEMMICK 90 Fig. 7 for other masses  $100\text{--}10000 m_p$ .

<sup>4</sup> Bound valid up to  $m_{X^-} \sim 100 \text{ TeV}$ .

NODE=S015CNM;LINKAGE=J1

NODE=S015CNM;LINKAGE=J2

NODE=S015CNM;LINKAGE=B

NODE=S015CNM;LINKAGE=A

**GENERAL NEW PHYSICS SEARCHES**

This subsection lists some of the search experiments which look for general signatures characteristic of new physics, independent of the framework of a specific model.

The observed events are compatible with Standard Model expectation, unless noted otherwise.

NODE=S015NPH

NODE=S015NPH

VALUE	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
	1 AGUILAR-AR...20B	CONN	$\nu$ elastic scatter on nuclei
	2 FEDDERKE 20		CHAMPs from white dwarfs
	3 SIRUNYAN 20A	CMS	SUSY/LQ search with mT2 or long-lived charged particles
	4 ALCANTARA 19		Auger, superheavy DM
	5 PORAYKO 18	PPTA	pulsar timing fuzzy DM search
	6 AAD 15AT	ATLS	$t + \cancel{E}_T$
	7 KHACHATRY...15F	CMS	$t + \cancel{E}_T$
	8 AALTONEN 14J	CDF	$W + 2 \text{ jets}$
	9 AAD 13A	ATLS	$WW \rightarrow \ell\nu\ell'\nu$
	10 AAD 13C	ATLS	$\gamma + \cancel{E}_T$
	11 AALTONEN 13I	CDF	Delayed $\gamma + \cancel{E}_T$
	12 CHATRCHYAN 13	CMS	$\ell^+\ell^- + \text{jets} + \cancel{E}_T$
	13 AAD 12C	ATLS	$t\bar{t} + \cancel{E}_T$
	14 AALTONEN 12M	CDF	jet + $\cancel{E}_T$
	15 CHATRCHYAN 12AP	CMS	jet + $\cancel{E}_T$
	16 CHATRCHYAN 12Q	CMS	$Z + \text{jets} + \cancel{E}_T$
	17 CHATRCHYAN 12T	CMS	$\gamma + \cancel{E}_T$
	18 AAD 11S	ATLS	jet + $\cancel{E}_T$
	19 AALTONEN 11AF	CDF	$\ell^\pm \ell^\pm$
	20 CHATRCHYAN 11C	CMS	$\ell^+\ell^- + \text{jets} + \cancel{E}_T$
	21 CHATRCHYAN 11U	CMS	jet + $\cancel{E}_T$
	22 AALTONEN 10AF	CDF	$\gamma\gamma + \ell, \cancel{E}_T$
	23 AALTONEN 09AF	CDF	$\ell\gamma b \cancel{E}_T$
	24 AALTONEN 09G	CDF	$\ell\ell\ell \cancel{E}_T$

NODE=S015NPH

1 AGUILAR-AREVALO 20B search for light BSM mediator effect on $\nu$ elastic scatter on nuclei; no signal; limits placed in $m(\text{mediator})$ vs. coupling plane for two models of MeV-scale mediators.	NODE=S015NPH;LINKAGE=I
2 FEDDERKE 20 place limits on cosmic relic charged massive particles (CHAMPs) due to their capture and subsequent disruption of old white dwarf stars; limits placed in the $m(\text{CHAMP})$ vs. relic density parameter plane.	NODE=S015NPH;LINKAGE=J
3 SIRUNYAN 20A search for SUSY and LQ production using mT2 or presence of long-lived charged particle; no signal, limits placed in various mass planes for different BSM scenarios and various assumed lifetimes.	NODE=S015NPH;LINKAGE=H
4 ALCANTARA 19 place limits on $m(\text{WIMPzilla}=X)$ vs lifetime from upper bound on ultra high energy cosmic rays at Auger experiment: e.g. $\tau(X) < 4 \times 10^{22}$ yr for $m(X) = 10^{16}$ GeV.	NODE=S015NPH;LINKAGE=F
5 PORAYKO 18 search for deviations in the residuals of pulsar timing data using PPTA. No signal observed. Limits set on fuzzy DM with $3 \times 10^{-24} < m(\text{DM}) < 2 \times 10^{-22}$ eV.	NODE=S015NPH;LINKAGE=E
6 AAD 15AT search for events with a top quark and missing $E_T$ in $pp$ collisions at $E_{\text{cm}} = 8$ TeV with $L = 20.3 \text{ fb}^{-1}$ .	NODE=S015NPH;LINKAGE=C
7 KHACHATRYAN 15F search for events with a top quark and missing $E_T$ in $pp$ collisions at $E_{\text{cm}} = 8$ TeV with $L = 19.7 \text{ fb}^{-1}$ .	NODE=S015NPH;LINKAGE=D
8 AALTONEN 14J examine events with a $W$ and two jets in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 8.9 \text{ fb}^{-1}$ . Invariant mass distributions of the two jets are consistent with the Standard Model expectation.	NODE=S015NPH;LINKAGE=B
9 AAD 13A search for resonant $WW$ production in $pp$ collisions at $E_{\text{cm}} = 7$ TeV with $L = 4.7 \text{ fb}^{-1}$ .	NODE=S015NPH;LINKAGE=DD
10 AAD 13C search for events with a photon and missing $E_T$ in $pp$ collisions at $E_{\text{cm}} = 7$ TeV with $L = 4.6 \text{ fb}^{-1}$ .	NODE=S015NPH;LINKAGE=GA
11 AALTONEN 13I search for events with a photon and missing $E_T$ , where the photon is detected after the expected timing, in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 6.3 \text{ fb}^{-1}$ . The data are consistent with the Standard Model expectation.	NODE=S015NPH;LINKAGE=A
12 CHATRCHYAN 13 search for events with an opposite-sign lepton pair, jets, and missing $E_T$ in $pp$ collisions at $E_{\text{cm}} = 7$ TeV with $L = 4.98 \text{ fb}^{-1}$ .	NODE=S015NPH;LINKAGE=CY
13 AAD 12C search for events with a $t\bar{t}$ pair and missing $E_T$ in $pp$ collisions at $E_{\text{cm}} = 7$ TeV with $L = 1.04 \text{ fb}^{-1}$ .	NODE=S015NPH;LINKAGE=DA
14 AALTONEN 12M search for events with a jet and missing $E_T$ in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 6.7 \text{ fb}^{-1}$ .	NODE=S015NPH;LINKAGE=AN
15 CHATRCHYAN 12AP search for events with a jet and missing $E_T$ in $pp$ collisions at $E_{\text{cm}} = 7$ TeV with $L = 5.0 \text{ fb}^{-1}$ .	NODE=S015NPH;LINKAGE=CC
16 CHATRCHYAN 12Q search for events with a $Z$ , jets, and missing $E_T$ in $pp$ collisions at $E_{\text{cm}} = 7$ TeV with $L = 4.98 \text{ fb}^{-1}$ .	NODE=S015NPH;LINKAGE=CT
17 CHATRCHYAN 12T search for events with a photon and missing $E_T$ in $pp$ collisions at $E_{\text{cm}} = 7$ TeV with $L = 5.0 \text{ fb}^{-1}$ .	NODE=S015NPH;LINKAGE=CR
18 AAD 11S search for events with one jet and missing $E_T$ in $pp$ collisions at $E_{\text{cm}} = 7$ TeV with $L = 33 \text{ pb}^{-1}$ .	NODE=S015NPH;LINKAGE=AD
19 AALTONEN 11AF search for high- $p_T$ like-sign dileptons in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 6.1 \text{ fb}^{-1}$ .	NODE=S015NPH;LINKAGE=AO
20 CHATRCHYAN 11C search for events with an opposite-sign lepton pair, jets, and missing $E_T$ in $pp$ collisions at $E_{\text{cm}} = 7$ TeV with $L = 34 \text{ pb}^{-1}$ .	NODE=S015NPH;LINKAGE=CA
21 CHATRCHYAN 11U search for events with one jet and missing $E_T$ in $pp$ collisions at $E_{\text{cm}} = 7$ TeV with $L = 36 \text{ pb}^{-1}$ .	NODE=S015NPH;LINKAGE=CH
22 AALTONEN 10AF search for $\gamma\gamma$ events with $e, \mu, \tau$ , or missing $E_T$ in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 1.1\text{--}2.0 \text{ fb}^{-1}$ .	NODE=S015NPH;LINKAGE=AT
23 AALTONEN 09AF search for $\ell\gamma b$ events with missing $E_T$ in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 1.9 \text{ fb}^{-1}$ . The observed events are compatible with Standard Model expectation including $t\bar{t}\gamma$ production.	NODE=S015NPH;LINKAGE=AL
24 AALTONEN 09G search for $\mu\mu\mu$ and $\mu\mu e$ events with missing $E_T$ in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96$ TeV with $L = 976 \text{ pb}^{-1}$ .	NODE=S015NPH;LINKAGE=AA

## LIMITS ON JET-JET RESONANCES

NODE=S015420

### Heavy Particle Production Cross Section

Limits are for a particle decaying to two hadronic jets.

Units(pb)	CL%	Mass(GeV)	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

1	AAD	20AD	ATLS	$pp$ at 13 TeV, dijet resonance
2	AAD	20T	ATLS	dijet resonance search
3	AAD	20W	ATLS	dijet resonance plus lepton

		4	SIRUNYAN	20AI	CMS	dijet resonance search		
		5	AABOUD	19AJ	ATLS	$pp \rightarrow \gamma X, X \rightarrow jj$		
		6	SIRUNYAN	19B	CMS	$pp \rightarrow jA, A \rightarrow b\bar{b}$		
		7	SIRUNYAN	19CD	CMS	$pp \rightarrow Z'\gamma, Z' \rightarrow jj$		
		8	AABOUD	18AD	ATLS	$pp \rightarrow Y \rightarrow HX \rightarrow (bb) + (qq)$		
		9	AABOUD	18CK	ATLS	$pp \rightarrow bbb + \cancel{E}_T$		
		10	AABOUD	18CL	ATLS	$pp \rightarrow$ vector-like quarks		
		11	AABOUD	18N	ATLS	$pp \rightarrow jj$ resonance		
		12	SIRUNYAN	18DJ	CMS	$pp \rightarrow ZZ$ or $WZ \rightarrow \ell\bar{\ell}jj$		
		13	SIRUNYAN	18DY	CMS	$pp \rightarrow RR; R \rightarrow jj$		
		14	KHACHATRYAN	17W	CMS	$pp \rightarrow jj$ resonance		
		15	KHACHATRYAN	17Y	CMS	$pp \rightarrow (8-10) j + \cancel{E}_T$		
		16	SIRUNYAN	17F	CMS	$pp \rightarrow jj$ angular distribution		
		17	AABOUD	16	ATLS	$pp \rightarrow b +$ jet		
		18	AAD	16N	ATLS	$pp \rightarrow$ 3 high $E_T$ jets		
		19	AAD	16S	ATLS	$pp \rightarrow jj$ resonance		
		20	KHACHATRYAN	16K	CMS	$pp \rightarrow jj$ resonance		
		21	KHACHATRYAN	16L	CMS	$pp \rightarrow jj$ resonance		
		22	AAD	13D	ATLS	7 TeV $pp \rightarrow$ 2 jets		
		23	AALTONEN	13R	CDF	1.96 TeV $p\bar{p} \rightarrow$ 4 jets		
		24	CHATRCHYAN	13A	CMS	7 TeV $pp \rightarrow$ 2 jets		
		25	CHATRCHYAN	13A	CMS	7 TeV $pp \rightarrow b\bar{b}X$	OCCUR=2	
		26	AAD	12S	ATLS	7 TeV $pp \rightarrow$ 2 jets		
		27	CHATRCHYAN	12BL	CMS	7 TeV $pp \rightarrow t\bar{t}X$		
		28	AAD	11AG	ATLS	7 TeV $pp \rightarrow$ 2 jets		
		29	AALTONEN	11M	CDF	1.96 TeV $p\bar{p} \rightarrow W +$ 2 jets		
		30	ABAZOV	11I	D0	1.96 TeV $p\bar{p} \rightarrow W +$ 2 jets		
		31	AAD	10	ATLS	7 TeV $pp \rightarrow$ 2 jets		
		32	KHACHATRYAN	10	CMS	7 TeV $pp \rightarrow$ 2 jets		
		33	ABE	99F	CDF	1.8 TeV $p\bar{p} \rightarrow b\bar{b} +$ anything		
		34	ABE	97G	CDF	1.8 TeV $p\bar{p} \rightarrow$ 2 jets		
<2603	95	200	35	ABE	93G	CDF	1.8 TeV $p\bar{p} \rightarrow$ 2 jets	
< 44	95	400	35	ABE	93G	CDF	1.8 TeV $p\bar{p} \rightarrow$ 2 jets	OCCUR=2
< 7	95	600	35	ABE	93G	CDF	1.8 TeV $p\bar{p} \rightarrow$ 2 jets	OCCUR=3
		1	AAD	20AD		search for weakly supervised dijet resonance in ATLAS with 139 fb <sup>-1</sup> at 13 TeV; no signal; various limits placed depending on kinematics and production cross section.	NODE=S015HP;LINKAGE=X	
		2	AAD	20T		search for dijet resonance with or without $b$ -jets at 13 TeV and 139 fb <sup>-1</sup> ; no signal; limits placed in $\sigma \cdot$ BF vs mass plane for various BSM models.	NODE=S015HP;LINKAGE=U	
		3	AAD	20W		search for dijet resonance plus lepton with ATLAS at 13 TeV and 139 fb <sup>-1</sup> ; no signal; limits placed in $\sigma \cdot$ BF vs. mass plane for various BSM models.	NODE=S015HP;LINKAGE=V	
		4	SIRUNYAN	20AI		search for dijet resonance in CMS at 13 TeV with 137 fb <sup>-1</sup> ; no signal; limits set in $\sigma$ vs. mass plane for various BSM models.	NODE=S015HP;LINKAGE=W	
		5	AABOUD	19AJ		search for low mass dijet resonance in $pp \rightarrow \gamma X, X \rightarrow jj$ at 13 TeV with 79.8 fb <sup>-1</sup> of data; no signal found; limits placed on $Z'$ model in coupling vs. $m(Z')$ plane.	NODE=S015HP;LINKAGE=S	
		6	SIRUNYAN	19B		search for low mass resonance $pp \rightarrow jA, A \rightarrow b\bar{b}$ at 13 TeV using 35.9 fb <sup>-1</sup> ; no signal; exclude resonances 50–350 GeV depending on production and decay.	NODE=S015HP;LINKAGE=R	
		7	SIRUNYAN	19CD		search for $pp \rightarrow Z'\gamma, Z' \rightarrow jj$ with fat jet ( $jj$ ); no signal, limits placed in $m(Z')$ vs. coupling plane for $Z'$ masses from 10 to 125 GeV.	NODE=S015HP;LINKAGE=T	
		8	AABOUD	18AD		search for new heavy particle $Y \rightarrow HX \rightarrow (bb) + (qq)$ . No signal observed. Limits set on $m(Y)$ vs. $m(X)$ in the ranges of $m(Y)$ in 1–4 TeV and $m(X)$ in 50–1000 GeV.	NODE=S015HP;LINKAGE=L	
		9	AABOUD	18CK		search for SUSY Higgsinos in gauge-mediation via $pp \rightarrow bbb + \cancel{E}_T$ at 13 TeV using two complementary analyses with 24.3/36.1 fb <sup>-1</sup> ; no signal is found and Higgsinos with masses between 130 and 230 GeV and between 290 and 880 GeV are excluded at the 95% confidence level.	NODE=S015HP;LINKAGE=N	
		10	AABOUD	18CL		search for $pp \rightarrow$ vector-like quarks $\rightarrow$ jets at 13 TeV with 36 fb <sup>-1</sup> ; no signal seen; limits set on various VLQ scenarios. For pure $B \rightarrow Hb$ or $T \rightarrow Ht$ , set the mass limit $m > 1010$ GeV.	NODE=S015HP;LINKAGE=O	
		11	AABOUD	18N		search for dijet resonance at Atlas with 13 TeV and 29.3 fb <sup>-1</sup> ; limits set on $m(Z')$ in the mass range of 450–1800 GeV.	NODE=S015HP;LINKAGE=M	
		12	SIRUNYAN	18DJ		search for $pp \rightarrow ZZ$ or $WZ \rightarrow \ell\bar{\ell}jj$ resonance at 13 TeV, 35.9 fb <sup>-1</sup> ; no signal; limits set in the 400–4500 GeV mass range, exclusion of $W'$ up to 2270 GeV in the HVT model A, and up to 2330 GeV for HVT model B. WED bulk graviton exclusion up to 925 GeV.	NODE=S015HP;LINKAGE=P	
		13	SIRUNYAN	18DY		search for $pp \rightarrow RR; R \rightarrow jj$ two dijet resonances at 13 TeV 35.9 fb <sup>-1</sup> ; no signal; limits placed on RPV top-squark pair production.	NODE=S015HP;LINKAGE=Q	
		14	KHACHATRYAN	17W		search for dijet resonance in 12.9 fb <sup>-1</sup> data at 13 TeV; see Fig. 2 for limits on axiglouons, diquarks, dark matter mediators etc.	NODE=S015HP;LINKAGE=I	

15 KHACHATRYAN 17Y search for $pp \rightarrow (8-10)j$ in $19.7 \text{ fb}^{-1}$ at 8 TeV. No signal seen. Limits set on colorons, axigluons, RPV, and SUSY.	NODE=S015HP;LINKAGE=J
16 SIRUNYAN 17F measure $pp \rightarrow jj$ angular distribution in $2.6 \text{ fb}^{-1}$ at 13 TeV; limits set on LEDs and quantum black holes.	NODE=S015HP;LINKAGE=K
17 AABOUD 16 search for resonant dijets including one or two $b$ -jets with $3.2 \text{ fb}^{-1}$ at 13 TeV; exclude excited $b^*$ quark from 1.1–2.1 TeV; exclude leptophilic $Z'$ with SM couplings from 1.1–1.5 TeV.	NODE=S015HP;LINKAGE=F
18 AAD 16N search for $\geq 3$ jets with $3.6 \text{ fb}^{-1}$ at 13 TeV; limits placed on micro black holes (Fig. 10) and string balls (Fig. 11).	NODE=S015HP;LINKAGE=D
19 AAD 16S search for high mass jet-jet resonance with $3.6 \text{ fb}^{-1}$ at 13 TeV; exclude portions of excited quarks, $W'$ , $Z'$ and contact interaction parameter space.	NODE=S015HP;LINKAGE=E
20 KHACHATRYAN 16K search for dijet resonance in $2.4 \text{ fb}^{-1}$ data at 13 TeV; see Fig. 3 for limits on axigluons, diquarks etc.	NODE=S015HP;LINKAGE=G
21 KHACHATRYAN 16L use data scouting technique to search for $jj$ resonance on $18.8 \text{ fb}^{-1}$ of data at 8 TeV. Limits on the coupling of a leptophobic $Z'$ to quarks are set, improving on the results by other experiments in the mass range between 500–800 GeV.	NODE=S015HP;LINKAGE=H
22 AAD 13D search for dijet resonances in $pp$ collisions at $E_{\text{cm}} = 7 \text{ TeV}$ with $L = 4.8 \text{ fb}^{-1}$ . The observed events are compatible with Standard Model expectation. See their Fig. 6 and Table 2 for limits on resonance cross section in the range $m = 1.0\text{--}4.0 \text{ TeV}$ .	NODE=S015HP;LINKAGE=GA
23 AALTONEN 13R search for production of a pair of jet-jet resonances in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96 \text{ TeV}$ with $L = 6.6 \text{ fb}^{-1}$ . See their Fig. 5 and Tables I, II for cross section limits.	NODE=S015HP;LINKAGE=C
24 CHATRCHYAN 13A search for $qq$ , $qg$ , and $gg$ resonances in $pp$ collisions at $E_{\text{cm}} = 7 \text{ TeV}$ with $L = 4.8 \text{ fb}^{-1}$ . See their Fig. 3 and Table 1 for limits on resonance cross section in the range $m = 1.0\text{--}4.3 \text{ TeV}$ .	NODE=S015HP;LINKAGE=CA
25 CHATRCHYAN 13A search for $b\bar{b}$ resonances in $pp$ collisions at $E_{\text{cm}} = 7 \text{ TeV}$ with $L = 4.8 \text{ fb}^{-1}$ . See their Fig. 8 and Table 4 for limits on resonance cross section in the range $m = 1.0\text{--}4.0 \text{ TeV}$ .	NODE=S015HP;LINKAGE=CT
26 AAD 12S search for dijet resonances in $pp$ collisions at $E_{\text{cm}} = 7 \text{ TeV}$ with $L = 1.0 \text{ fb}^{-1}$ . See their Fig. 3 and Table 2 for limits on resonance cross section in the range $m = 0.9\text{--}4.0 \text{ TeV}$ .	NODE=S015HP;LINKAGE=DA
27 CHATRCHYAN 12BL search for $t\bar{t}$ resonances in $pp$ collisions at $E_{\text{cm}} = 7 \text{ TeV}$ with $L = 4.4 \text{ fb}^{-1}$ . See their Fig. 4 for limits on resonance cross section in the range $m = 0.5\text{--}3.0 \text{ TeV}$ .	NODE=S015HP;LINKAGE=CH
28 AAD 11AG search for dijet resonances in $pp$ collisions at $E_{\text{cm}} = 7 \text{ TeV}$ with $L = 36 \text{ pb}^{-1}$ . Limits on number of events for $m = 0.6\text{--}4 \text{ TeV}$ are given in their Table 3.	NODE=S015HP;LINKAGE=AD
29 AALTONEN 11M find a peak in two jet invariant mass distribution around 140 GeV in $W + 2$ jet events in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96 \text{ TeV}$ with $L = 4.3 \text{ fb}^{-1}$ .	NODE=S015HP;LINKAGE=AL
30 ABAZOV 11I search for two-jet resonances in $W + 2$ jet events in $p\bar{p}$ collisions at $E_{\text{cm}} = 1.96 \text{ TeV}$ with $L = 4.3 \text{ fb}^{-1}$ and give limits $\sigma < (2.6\text{--}1.3) \text{ pb}$ (95% CL) for $m = 110\text{--}170 \text{ GeV}$ . The result is incompatible with AALTONEN 11M.	NODE=S015HP;LINKAGE=AZ
31 AAD 10 search for narrow dijet resonances in $pp$ collisions at $E_{\text{cm}} = 7 \text{ TeV}$ with $L = 315 \text{ nb}^{-1}$ . Limits on the cross section in the range $10\text{--}10^3 \text{ pb}$ is given for $m = 0.3\text{--}1.7 \text{ TeV}$ .	NODE=S015HP;LINKAGE=AA
32 KHACHATRYAN 10 search for narrow dijet resonances in $pp$ collisions at $E_{\text{cm}} = 7 \text{ TeV}$ with $L = 2.9 \text{ pb}^{-1}$ . Limits on the cross section in the range $1\text{--}300 \text{ pb}$ is given for $m = 0.5\text{--}2.6 \text{ TeV}$ separately in the final states $qq$ , $qg$ , and $gg$ .	NODE=S015HP;LINKAGE=KH
33 ABE 99F search for narrow $b\bar{b}$ resonances in $p\bar{p}$ collisions at $E_{\text{cm}}=1.8 \text{ TeV}$ . Limits on $\sigma(p\bar{p} \rightarrow X + \text{anything}) \cdot B(X \rightarrow b\bar{b})$ in the range $3\text{--}10^3 \text{ pb}$ (95%CL) are given for $m_X=200\text{--}750 \text{ GeV}$ . See their Table I.	NODE=S015HP;LINKAGE=FH
34 ABE 97G search for narrow dijet resonances in $p\bar{p}$ collisions with $106 \text{ pb}^{-1}$ of data at $E_{\text{cm}} = 1.8 \text{ TeV}$ . Limits on $\sigma(p\bar{p} \rightarrow X + \text{anything}) \cdot B(X \rightarrow jj)$ in the range $10^4\text{--}10^{-1} \text{ pb}$ (95%CL) are given for dijet mass $m=200\text{--}1150 \text{ GeV}$ with both jets having $ \eta  < 2.0$ and the dijet system having $ \cos\theta^*  < 0.67$ . See their Table I for the list of limits. Supersedes ABE 93G.	NODE=S015HP;LINKAGE=B
35 ABE 93G give cross section times branching ratio into light ( $d$ , $u$ , $s$ , $c$ , $b$ ) quarks for $\Gamma = 0.02 M$ . Their Table II gives limits for $M = 200\text{--}900 \text{ GeV}$ and $\Gamma = (0.02\text{--}0.2) M$ .	NODE=S015HP;LINKAGE=A

## LIMITS ON NEUTRAL PARTICLE PRODUCTION

### Production Cross Section of Radiatively-Decaying Neutral Particle

VALUE (pb)	CL%	DOCUMENT ID	TECN	COMMENT
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••• We do not use the following data for averages, fits, limits, etc. •••

		1 ALBERT	18C HAWC	$\gamma$ from Sun
		2 KHACHATRY...17D	CMS	$Z\gamma$ resonance
<0.0008	95	3 AAD	16AI ATLS	$pp \rightarrow \gamma + \text{jet}$
		4 KHACHATRY...16M	CMS	$pp \rightarrow \gamma\gamma$ resonance
<(0.043–0.17)	95	5 ABBIENDI	00D OPAL	$e^+e^- \rightarrow X^0\gamma^0$ , $X^0 \rightarrow \gamma^0\gamma$

NODE=S015415

NODE=S015GAM  
NODE=S015GAM

OCCUR=2

<(0.05–0.8)	95	<sup>6</sup> ABBIENDI	00D	OPAL	$e^+e^- \rightarrow X^0X^0,$ $X^0 \rightarrow \gamma^0\gamma$	OCCUR=2
<(2.5–0.5)	95	<sup>7</sup> ACKERSTAFF	97B	OPAL	$e^+e^- \rightarrow X^0\gamma^0,$ $X^0 \rightarrow \gamma^0\gamma$	OCCUR=2
<(1.6–0.9)	95	<sup>8</sup> ACKERSTAFF	97B	OPAL	$e^+e^- \rightarrow X^0X^0,$ $X^0 \rightarrow \gamma^0\gamma$	OCCUR=2
<sup>1</sup> ALBERT 18C search for WIMP annihilation in Sun to long-lived, radiatively decaying mediator; no signal; limits set on $\sigma^{SD}(\chi p)$ assuming long-lived mediator.						NODE=S015GAM;LINKAGE=G
<sup>2</sup> KHACHATRYAN 17D search for new scalar resonance decaying to $Z\gamma$ with $Z \rightarrow e^+e^-$ , $\mu^+\mu^-$ in $pp$ collisions at 8 and 13 TeV; no signal seen.						NODE=S015GAM;LINKAGE=F
<sup>3</sup> AAD 16Al search for excited quarks (EQ) and quantum black holes (QBH) in 3.2 fb <sup>-1</sup> at 13 TeV of data; exclude EQ below 4.4 TeV and QBH below 3.8 (6.2) TeV for RS1 (ADD) models. The visible cross section limit was obtained for 5 TeV resonance with $\sigma_G/M_G = 2\%$ .						NODE=S015GAM;LINKAGE=C
<sup>4</sup> KHACHATRYAN 16M search for $\gamma\gamma$ resonance using 19.7 fb <sup>-1</sup> at 8 TeV and 3.3 fb <sup>-1</sup> at 13 TeV; slight excess at 750 GeV noted; limit set on RS graviton.						NODE=S015GAM;LINKAGE=D
<sup>5</sup> ABBIENDI 00D associated production limit is for $m_{X^0} = 90\text{--}188$ GeV, $m_{\gamma^0} = 0$ at $E_{cm} = 189$ GeV. See also their Fig. 9.						NODE=S015GAM;LINKAGE=G1
<sup>6</sup> ABBIENDI 00D pair production limit is for $m_{X^0} = 45\text{--}94$ GeV, $m_{\gamma^0} = 0$ at $E_{cm} = 189$ GeV. See also their Fig. 12.						NODE=S015GAM;LINKAGE=G2
<sup>7</sup> ACKERSTAFF 97B associated production limit is for $m_{X^0} = 80\text{--}160$ GeV, $m_{\gamma^0} = 0$ from 10.0 pb <sup>-1</sup> at $E_{cm} = 161$ GeV. See their Fig. 3(a).						NODE=S015GAM;LINKAGE=A
<sup>8</sup> ACKERSTAFF 97B pair production limit is for $m_{X^0} = 40\text{--}80$ GeV, $m_{\gamma^0} = 0$ from 10.0 pb <sup>-1</sup> at $E_{cm} = 161$ GeV. See their Fig. 3(b).						NODE=S015GAM;LINKAGE=B

### Heavy Particle Production Cross Section

VALUE (cm <sup>2</sup> /N)	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
		<sup>1</sup> AAIJ	20AL	LHCB $pp$ at 13 TeV, dimuon resonance
		<sup>2</sup> SIRUNYAN	20AY	CMS $\gamma(15)\mu^+\mu^-$ decay states
		<sup>3</sup> SIRUNYAN	20Z	CMS multilepton BSM search, 13 TeV
		<sup>4</sup> AABOUD	19H	ATLS di-photon-jet resonance
		<sup>5</sup> AABOUD	19V	ATLS review, mediator-based DM
		<sup>6</sup> SIRUNYAN	19O	CMS $pp \rightarrow \gamma \cancel{E}_T$
		<sup>7</sup> AABOUD	18CJ	ATLS $pp \rightarrow VV/\ell\ell/\ell\nu$ , $V = W, Z, h$
		<sup>8</sup> AABOUD	18CM	ATLS $pp \rightarrow e\mu/e\tau/\mu\tau$
		<sup>9</sup> AAIJ	18AJ	LHCB $pp \rightarrow A' \rightarrow \mu^+\mu^-$ ; dark photon
		<sup>10</sup> BANERJEE	18	NA64 $eZ \rightarrow eZX(A')$
		<sup>11</sup> BANERJEE	18A	NA64 $eZ \rightarrow eZA', A' \rightarrow \chi\chi$
		<sup>12</sup> MARSICANO	18	E137 $e^+e^- \rightarrow A'(\gamma)$ visible decay
		<sup>13</sup> SIRUNYAN	18BB	CMS $pp \rightarrow Z' \rightarrow \ell^+\ell^-$ at 13 TeV
		<sup>14</sup> SIRUNYAN	18DA	CMS $pp \rightarrow$ Black Hole, string ball, sphaleron
		<sup>15</sup> SIRUNYAN	18DD	CMS $pp \rightarrow jj$
		<sup>16</sup> SIRUNYAN	18DR	CMS $pp \rightarrow b\mu\bar{\mu}$
		<sup>17</sup> SIRUNYAN	18DU	CMS $pp \rightarrow \gamma\gamma$
		<sup>18</sup> SIRUNYAN	18ED	CMS $pp \rightarrow V \rightarrow Wh; h \rightarrow b\bar{b}; W \rightarrow \ell\nu$
		<sup>19</sup> AABOUD	17B	ATLS $WH, ZH$ resonance
		<sup>20</sup> AAIJ	17BR	LHCB $pp \rightarrow \pi_\nu\pi_\nu, \pi_\nu \rightarrow jj$
		<sup>21</sup> AAD	16O	ATLS $\ell + (\ell s \text{ or jets})$
		<sup>22</sup> AAD	16R	ATLS $WW, WZ, ZZ$ resonance
		<sup>23</sup> KRASZNAHO...16		$p^7\text{Li} \rightarrow {}^8\text{Be} \rightarrow X(17)N,$ $X(17) \rightarrow e^+e^-$
		<sup>24</sup> LEES	15E	BABR $e^+e^-$ collisions
		<sup>25</sup> ADAMS	97B	KTEV $m = 1.2\text{--}5$ GeV
< 10 <sup>-36</sup> –10 <sup>-33</sup>	90	<sup>26</sup> GALLAS	95	TOF $m = 0.5\text{--}20$ GeV
<(4–0.3) × 10 <sup>-31</sup>	95	<sup>27</sup> AKESSON	91	CNTR $m = 0\text{--}5$ GeV
<2 × 10 <sup>-36</sup>	90	<sup>28</sup> BADIER	86	BDMP $\tau = (0.05\text{--}1.) \times 10^{-8}\text{s}$
<2.5 × 10 <sup>-35</sup>		<sup>29</sup> GUSTAFSON	76	CNTR $\tau > 10^{-7}$ s

NODE=S015CS  
NODE=S015CS

- |    |   |                        |
|----|---|------------------------|
| 1  | AAIJ 20AL search for dimuon resonance from promptly decaying $X$ particle; no signal; limits placed on $m(X)$ up to 60 GeV depending on mixing in 2HDM .  | NODE=S015CS;LINKAGE=DA |
| 2  | SIRUNYAN 20AY measured $\Upsilon(1S)$ pair production cross section and searched for new states decaying into $\Upsilon(1S)\mu^+\mu^-$ at CMS with 13 TeV with $35.9 \text{ fb}^{-1}$ . No signal is found and limits are set in $\sigma \cdot \text{BF}$ vs. mass plane for tetra- $b$ -quarks with masses between 17.5 and 19 GeV and for generic search for narrow resonances with mass between 16.5 and 27 GeV. | NODE=S015CS;LINKAGE=BA |
| 3  | SIRUNYAN 20Z search for BSM physics via multilepton production with CMS at 13 TeV with $137 \text{ fb}^{-1}$ ; no signal is found and limits are set on type-III seesaw and other BSM models.   | NODE=S015CS;LINKAGE=CA |
| 4  | AABOUD 19H searches for di-photon-jet resonance at 13 TeV and $36.7 \text{ fb}^{-1}$ of data; no signal found and limits placed on $\sigma \cdot \text{BR}$ vs. mass plane for various simplified models.   | NODE=S015CS;LINKAGE=Z  |
| 5  | AABOUD 19V review ATLAS searches for mediator-based DM at 7, 8, and 13 TeV with up to $37 \text{ fb}^{-1}$ of data; no signal found and limits set for wide variety of simplified models of dark matter.  | NODE=S015CS;LINKAGE=AA |
| 6  | SIRUNYAN 19O search for $pp \rightarrow \gamma \cancel{E}_T$ at 13 TeV with $36.1 \text{ fb}^{-1}$ ; no signal found and limits set for various simplified models.  | NODE=S015CS;LINKAGE=Y  |
| 7  | AABOUD 18CJ make multichannel search for $pp \rightarrow VV/\ell\ell/\ell\nu$ , $V = W, Z, h$ at 13 TeV, $36.1 \text{ fb}^{-1}$ ; no signal found; limits placed for several BSM models.  | NODE=S015CS;LINKAGE=R  |
| 8  | AABOUD 18CM search for lepton-flavor violating resonance in $pp \rightarrow e\mu/e\tau/\mu\tau$ at 13 TeV, $36.1 \text{ fb}^{-1}$ ; no signal is found and limits placed for various BSM models.  | NODE=S015CS;LINKAGE=S  |
| 9  | AAIJ 18AJ search for prompt and delayed dark photon decay $A' \rightarrow \mu^+\mu^-$ at LHCb detector using $1.6 \text{ fb}^{-1}$ of $pp$ collisions at 13 TeV; limits on $m(A')$ vs. kinetic mixing are set.  | NODE=S015CS;LINKAGE=K  |
| 10 | BANERJEE 18 search for dark photon $A'/16.7 \text{ MeV}$ boson $X$ at NA64 via $eZ \rightarrow eZX(A')$ ; no signal found and limits set on the $X$ - $e^-$ coupling $\epsilon_e$ in the range $1.3 \times 10^{-4} \leq \epsilon_e \leq 4.2 \times 10^{-4}$ excluding part of the allowed parameter space.  | NODE=S015CS;LINKAGE=L  |
| 11 | BANERJEE 18A search for invisibly decaying dark photons in $eZ \rightarrow eZA', A' \rightarrow \text{invisible}$ ; no signal found and limits set on mixing for $m(A') < 1 \text{ GeV}$ .  | NODE=S015CS;LINKAGE=M  |
| 12 | MARSICANO 18 search for dark photon $e^+e^- \rightarrow A'(\gamma)$ visible decay in SLAC E137 $e$ beam dump data. No signal observed and limits set in $\epsilon$ coupling vs $m(A')$ plane, see their figure 7.   | NODE=S015CS;LINKAGE=P  |
| 13 | SIRUNYAN 18BB search for high mass dilepton resonance; no signal found and exclude portions of $p$ -space of $Z'$ , KK graviton models.   | NODE=S015CS;LINKAGE=O  |
| 14 | SIRUNYAN 18DA search for $pp \rightarrow \text{Black Hole, string ball, sphaleron}$ via high multiplicity events at 13 TeV, $35.9 \text{ fb}^{-1}$ ; no signal, require e.g. $m(\text{BH}) > 10.1 \text{ TeV}$ .  | NODE=S015CS;LINKAGE=T  |
| 15 | SIRUNYAN 18DD search for $pp \rightarrow jj$ deviations in dijet angular distribution. No signal observed. Set limits on large extra dimensions, black holes and DM mediators e.g. $m(\text{BH}) > 5.9\text{--}8.2 \text{ TeV}$ .   | NODE=S015CS;LINKAGE=U  |
| 16 | SIRUNYAN 18DR search for dimuon resonance in $pp \rightarrow b\mu\bar{\mu}$ at 8 and 13 TeV. Slight excess seen at $m(\mu\bar{\mu}) \sim 28 \text{ GeV}$ in some channels.  | NODE=S015CS;LINKAGE=V  |
| 17 | SIRUNYAN 18DU search for high mass diphoton resonance in $pp \rightarrow \gamma\gamma$ at 13 TeV using $35.9 \text{ fb}^{-1}$ ; no signal; limits placed on RS Graviton, LED, and clockwork.  | NODE=S015CS;LINKAGE=W  |
| 18 | SIRUNYAN 18ED search for $pp \rightarrow V \rightarrow Wh; h \rightarrow b\bar{b}; W \rightarrow \ell\nu$ at 13 TeV with $35.9 \text{ fb}^{-1}$ ; no signal; limits set on $m(W')$ $> 2.9 \text{ TeV}$ .  | NODE=S015CS;LINKAGE=X  |
| 19 | AABOUD 17B exclude $m(W', Z') < 1.49\text{--}2.31 \text{ TeV}$ depending on the couplings and $W'/Z'$ degeneracy assumptions via $WH, ZH$ search in $pp$ collisions at 13 TeV with $3.2 \text{ fb}^{-1}$ of data.   | NODE=S015CS;LINKAGE=I  |
| 20 | AAIJ 17BR search for long-lived hidden valley pions from Higgs decay. Limits are set on the signal strength as a function of the mass and lifetime of the long-lived particle in their Fig. 4 and Tab. 4.   | NODE=S015CS;LINKAGE=J  |
| 21 | AAD 16O search for high $E_T \ell + (\ell\text{s or jets})$ with $3.2 \text{ fb}^{-1}$ at 13 TeV; exclude micro black holes mass $< 8 \text{ TeV}$ (Fig. 3) for models with two extra dimensions.   | NODE=S015CS;LINKAGE=G  |
| 22 | AAD 16R search for $WW, WZ, ZZ$ resonance in $20.3 \text{ fb}^{-1}$ at 8 TeV data; limits placed on massive RS graviton (Fig. 4).   | NODE=S015CS;LINKAGE=H  |
| 23 | KRASZNAHORKAY 16 report $p\text{Li} \rightarrow \text{Be} \rightarrow e\bar{e}N$ $5\sigma$ resonance at 16.7 MeV— possible evidence for nuclear interference or new light boson . However, such nuclear interference was ruled out already by ZANG 17.  | NODE=S015CS;LINKAGE=Q  |
| 24 | LEES 15E search for long-lived neutral particles produced in $e^+e^-$ collisions in the Upsilon region, which decays into $e^+e^-, \mu^+\mu^-, e^\pm\mu^\mp, \pi^+\pi^-, K^+K^-,$ or $\pi^\pm K^\mp$ . See their Fig. 2 for cross section limits.   | NODE=S015CS;LINKAGE=F  |
| 25 | ADAMS 97B search for a hadron-like neutral particle produced in $pN$ interactions, which decays into a $\rho^0$ and a weakly interacting massive particle. Upper limits are given for the ratio to $K_L$ production for the mass range 1.2–5 GeV and lifetime $10^{-9}\text{--}10^{-4} \text{ s}$ . See also our Light Gluino Section.  | NODE=S015CS;LINKAGE=E  |
| 26 | GALLAS 95 limit is for a weakly interacting neutral particle produced in 800 GeV/ $c$ $pN$ interactions decaying with a lifetime of $10^{-4}\text{--}10^{-8} \text{ s}$ . See their Figs. 8 and 9. Similar limits are obtained for a stable particle with interaction cross section $10^{-29}\text{--}10^{-33} \text{ cm}^2$ . See Fig. 10.   | NODE=S015CS;LINKAGE=C  |
| 27 | AKESSON 91 limit is from weakly interacting neutral long-lived particles produced in $pN$ reaction at 450 GeV/ $c$ performed at CERN SPS. Bourquin-Gaillard formula is used   | NODE=S015CS;LINKAGE=B  |

as the production model. The above limit is for  $\tau > 10^{-7}$  s. For  $\tau > 10^{-9}$  s,  $\sigma < 10^{-30}$  cm<sup>2</sup>/nucleon is obtained.

- 28 BADIÉ 86 looked for long-lived particles at 300 GeV  $\pi^-$  beam dump. The limit applies for nonstrongly interacting neutral or charged particles with mass  $> 2$  GeV. The limit applies for particle modes,  $\mu^+\pi^-$ ,  $\mu^+\mu^-$ ,  $\pi^+\pi^-X$ ,  $\pi^+\pi^-\pi^\pm$  etc. See their figure 5 for the contours of limits in the mass- $\tau$  plane for each mode.
- 29 GUSTAFSON 76 is a 300 GeV FNAL experiment looking for heavy ( $m > 2$  GeV) long-lived neutral hadrons in the M4 neutral beam. The above typical value is for  $m = 3$  GeV and assumes an interaction cross section of 1 mb. Values as a function of mass and interaction cross section are given in figure 2.

NODE=S015CS;LINKAGE=D

NODE=S015CS;LINKAGE=A

### Production of New Penetrating Non- $\nu$ Like States in Beam Dump

VALUE	DOCUMENT ID	TECN	COMMENT
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NODE=S015BD  
NODE=S015BD

- • • We do not use the following data for averages, fits, limits, etc. • • •

1	LOSECCO	81	CALO	28 GeV protons
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- 1 No excess neutral-current events leads to  $\sigma(\text{production}) \times \sigma(\text{interaction}) \times \text{acceptance} < 2.26 \times 10^{-71}$  cm<sup>4</sup>/nucleon<sup>2</sup> (CL = 90%) for light neutrals. Acceptance depends on models (0.1 to  $4. \times 10^{-4}$ ).

NODE=S015BD;LINKAGE=A

### LIMITS ON CHARGED PARTICLES IN $e^+e^-$

NODE=S015425

#### Heavy Particle Production Cross Section in $e^+e^-$

Ratio to  $\sigma(e^+e^- \rightarrow \mu^+\mu^-)$  unless noted. See also entries in Free Quark Search and Magnetic Monopole Searches.

NODE=S015EE

NODE=S015EE

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
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NODE=S015EE

- • • We do not use the following data for averages, fits, limits, etc. • • •

$< 1 \times 10^{-3}$	90	1	KILE	18	ALEP	$e^+e^- \rightarrow 4$ jets
		2	ABLIKIM	17AA	BES3	$e^+e^- \rightarrow \ell\bar{\ell}\gamma$
		3	ACKERSTAFF	98P	OPAL	$Q=1,2/3$ , $m=45-89.5$ GeV
		4	ABREU	97D	DLPH	$Q=1,2/3$ , $m=45-84$ GeV
		5	BARATE	97K	ALEP	$Q=1$ , $m=45-85$ GeV
$< 2 \times 10^{-5}$	95	6	AKERS	95R	OPAL	$Q=1$ , $m=5-45$ GeV
$< 1 \times 10^{-5}$	95	6	AKERS	95R	OPAL	$Q=2$ , $m=5-45$ GeV
$< 2 \times 10^{-3}$	90	7	BUSKULIC	93C	ALEP	$Q=1$ , $m=32-72$ GeV
$< (10^{-2}-1)$	95	8	ADACHI	90C	TOPZ	$Q=1$ , $m=1-16$ , 18-27 GeV
$< 7 \times 10^{-2}$	90	9	ADACHI	90E	TOPZ	$Q=1$ , $m=5-25$ GeV
$< 1.6 \times 10^{-2}$	95	10	KINOSHITA	82	PLAS	$Q=3-180$ , $m < 14.5$ GeV
$< 5.0 \times 10^{-2}$	90	11	BARTEL	80	JADE	$Q=(3,4,5)/3$ 2-12 GeV

OCCUR=2

- 1 KILE 18 investigate archived ALEPH  $e^+e^- \rightarrow 4$  jets data and see 4-5  $\sigma$  excess at 110 GeV.

NODE=S015EE;LINKAGE=I

- 2 ABLIKIM 17AA search for dark photon  $A \rightarrow \ell\bar{\ell}$  at 3.773 GeV with 2.93 fb<sup>-1</sup>. Limits are set in  $\epsilon$  vs  $m(A)$  plane.

NODE=S015EE;LINKAGE=H

- 3 ACKERSTAFF 98P search for pair production of long-lived charged particles at  $E_{\text{cm}}$  between 130 and 183 GeV and give limits  $\sigma < (0.05-0.2)$  pb (95%CL) for spin-0 and spin-1/2 particles with  $m=45-89.5$  GeV, charge 1 and 2/3. The limit is translated to the cross section at  $E_{\text{cm}}=183$  GeV with the  $s$  dependence described in the paper. See their Figs. 2-4.

NODE=S015EE;LINKAGE=EP

- 4 ABREU 97D search for pair production of long-lived particles and give limits  $\sigma < (0.4-2.3)$  pb (95%CL) for various center-of-mass energies  $E_{\text{cm}}=130-136$ , 161, and 172 GeV, assuming an almost flat production distribution in  $\cos\theta$ .

NODE=S015EE;LINKAGE=DE

- 5 BARATE 97K search for pair production of long-lived charged particles at  $E_{\text{cm}} = 130$ , 136, 161, and 172 GeV and give limits  $\sigma < (0.2-0.4)$  pb (95%CL) for spin-0 and spin-1/2 particles with  $m=45-85$  GeV. The limit is translated to the cross section at  $E_{\text{cm}}=172$  GeV with the  $E_{\text{cm}}$  dependence described in the paper. See their Figs. 2 and 3 for limits on  $J = 1/2$  and  $J = 0$  cases.

NODE=S015EE;LINKAGE=G

- 6 AKERS 95R is a CERN-LEP experiment with  $W_{\text{cm}} \sim m_Z$ . The limit is for the production of a stable particle in multihadron events normalized to  $\sigma(e^+e^- \rightarrow \text{hadrons})$ . Constant phase space distribution is assumed. See their Fig. 3 for bounds for  $Q = \pm 2/3$ ,  $\pm 4/3$ .

NODE=S015EE;LINKAGE=F

- 7 BUSKULIC 93C is a CERN-LEP experiment with  $W_{\text{cm}} = m_Z$ . The limit is for a pair or single production of heavy particles with unusual ionization loss in TPC. See their Fig. 5 and Table 1.

NODE=S015EE;LINKAGE=E

- 8 ADACHI 90C is a KEK-TRISTAN experiment with  $W_{\text{cm}} = 52-60$  GeV. The limit is for pair production of a scalar or spin-1/2 particle. See Figs. 3 and 4.

NODE=S015EE;LINKAGE=D

- 9 ADACHI 90E is KEK-TRISTAN experiment with  $W_{\text{cm}} = 52-61.4$  GeV. The above limit is for inclusive production cross section normalized to  $\sigma(e^+e^- \rightarrow \mu^+\mu^-) \cdot \beta(3-\beta^2)/2$ , where  $\beta = (1 - 4m^2/W_{\text{cm}}^2)^{1/2}$ . See the paper for the assumption about the production mechanism.

NODE=S015EE;LINKAGE=C

- 10 KINOSHITA 82 is SLAC PEP experiment at  $W_{\text{cm}} = 29$  GeV using lexan and <sup>39</sup>Cr plastic sheets sensitive to highly ionizing particles.

NODE=S015EE;LINKAGE=B

- 11 BARTEL 80 is DESY-PETRA experiment with  $W_{\text{cm}} = 27-35$  GeV. Above limit is for inclusive pair production and ranges between  $1. \times 10^{-1}$  and  $1. \times 10^{-2}$  depending on mass and production momentum distributions. (See their figures 9, 10, 11).

NODE=S015EE;LINKAGE=A

**Branching Fraction of  $Z^0$  to a Pair of Stable Charged Heavy Fermions**

VALUE	CL%	DOCUMENT ID	TECN	COMMENT
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• • • We do not use the following data for averages, fits, limits, etc. • • •

$<5 \times 10^{-6}$	95	<sup>1</sup> AKERS	95R OPAL	$m = 40.4\text{--}45.6$ GeV
$<1 \times 10^{-3}$	95	AKRAWY	900 OPAL	$m = 29\text{--}40$ GeV

<sup>1</sup> AKERS 95R give the 95% CL limit  $\sigma(X\bar{X})/\sigma(\mu\mu) < 1.8 \times 10^{-4}$  for the pair production of singly- or doubly-charged stable particles. The limit applies for the mass range 40.4–45.6 GeV for  $X^\pm$  and  $< 45.6$  GeV for  $X^{\pm\pm}$ . See the paper for bounds for  $Q = \pm 2/3, \pm 4/3$ .

NODE=S015Z  
NODE=S015Z

NODE=S015Z;LINKAGE=A

**LIMITS ON CHARGED PARTICLES IN HADRONIC REACTIONS**

NODE=S015430

**MASS LIMITS for Long-Lived Charged Heavy Fermions**

Limits are for spin 1/2 particles with no color and  $SU(2)_L$  charge. The electric charge  $Q$  of the particle (in the unit of  $e$ ) is therefore equal to its weak hypercharge. Pair production by Drell-Yan like  $\gamma$  and  $Z$  exchange is assumed to derive the limits.

NODE=S015DY

NODE=S015DY

VALUE (GeV)	CL%	DOCUMENT ID	TECN	COMMENT
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NODE=S015DY

• • • We do not use the following data for averages, fits, limits, etc. • • •

		<sup>1</sup> SIRUNYAN	20N CMS	disappearing track LLP
$>660$	95	<sup>2</sup> AAD	15BJ ATLS	$ Q  = 2$
$>200$	95	<sup>3</sup> CHATRCHYAN	13AB CMS	$ Q  = 1/3$
$>480$	95	<sup>3</sup> CHATRCHYAN	13AB CMS	$ Q  = 2/3$
$>574$	95	<sup>3</sup> CHATRCHYAN	13AB CMS	$ Q  = 1$
$>685$	95	<sup>3</sup> CHATRCHYAN	13AB CMS	$ Q  = 2$
$>140$	95	<sup>4</sup> CHATRCHYAN	13AR CMS	$ Q  = 1/3$
$>310$	95	<sup>4</sup> CHATRCHYAN	13AR CMS	$ Q  = 2/3$

OCCUR=2

OCCUR=3

OCCUR=4

OCCUR=2

<sup>1</sup> SIRUNYAN 20N search for LLPs using disappearing track signature at CMS at 13 TeV with  $101 \text{ fb}^{-1}$ ; no signal; limits placed on long-lived winos and higgsinos from SUSY depending on mass and lifetime: e.g. at 95% CL, for a purely higgsino neutralino,  $m(\text{chargino}) > 750$  (175) GeV for  $\tau = 3$  (0.05) ns, and for a purely wino neutralino,  $m(\text{chargino}) > 884$  (474) GeV for  $\tau = 3$  (0.2) ns.

NODE=S015DY;LINKAGE=D

<sup>2</sup> AAD 15BJ use  $20.3 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 8$  TeV. See paper for limits for  $|Q| = 3, 4, 5, 6$ .

NODE=S015DY;LINKAGE=C

<sup>3</sup> CHATRCHYAN 13AB use  $5.0 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7$  TeV and  $18.8 \text{ fb}^{-1}$  at  $E_{\text{cm}} = 8$  TeV. See paper for limits for  $|Q| = 3, 4, \dots, 8$ .

NODE=S015DY;LINKAGE=B

<sup>4</sup> CHATRCHYAN 13AR use  $5.0 \text{ fb}^{-1}$  of  $pp$  collisions at  $E_{\text{cm}} = 7$  TeV.

NODE=S015DY;LINKAGE=A

**Heavy Particle Production Cross Section**

VALUE (nb)	CL%	DOCUMENT ID	TECN	COMMENT
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NODE=S015CH  
NODE=S015CH

• • • We do not use the following data for averages, fits, limits, etc. • • •

		<sup>1</sup> SIRUNYAN	20C CMS	$4t$ search via multileptons
		<sup>2</sup> AABOUD	19AA ATLS	BSM search
		<sup>3</sup> AABOUD	19Q ATLS	single top +MET
		<sup>4</sup> AABOUD	17D ATLS	anomalous $W W jj, W Z jj$
		<sup>5</sup> AABOUD	17L ATLS	$m > 870$ GeV, $Z(\rightarrow \nu\nu)tX$
		<sup>6</sup> SIRUNYAN	17B CMS	$tH$
		<sup>7</sup> SIRUNYAN	17C CMS	$Z + (t \text{ or } b)$
		<sup>8</sup> SIRUNYAN	17J CMS	$X_{5/3} \rightarrow tW$
		<sup>9</sup> AAIJ	15BD LHCb	$m = 124\text{--}309$ GeV
		<sup>10</sup> AAD	13AH ATLS	$ q  = (2\text{--}6)e, m = 50\text{--}600$ GeV
$<1.2 \times 10^{-3}$	95	<sup>11</sup> AAD	11i ATLS	$ q  = 10e, m = 0.2\text{--}1$ TeV
$<1.0 \times 10^{-5}$	95	<sup>12,13</sup> AALTONEN	09Z CDF	$m > 100$ GeV, noncolored
$<4.8 \times 10^{-5}$	95	<sup>12,14</sup> AALTONEN	09Z CDF	$m > 100$ GeV, colored
$<0.31\text{--}0.04 \times 10^{-3}$	95	<sup>15</sup> ABZOV	09M D0	pair production
$<0.19$	95	<sup>16</sup> AKTAS	04C H1	$m = 3\text{--}10$ GeV
$<0.05$	95	<sup>17</sup> ABE	92J CDF	$m = 50\text{--}200$ GeV
$<30\text{--}130$		<sup>18</sup> CARROLL	78 SPEC	$m = 2\text{--}2.5$ GeV
$<100$		<sup>19</sup> LEIPUNER	73 CNTR	$m = 3\text{--}11$ GeV

OCCUR=2

<sup>1</sup> SIRUNYAN 20C search for four top-quark production with decay to multileptons at CMS at 13 TeV with  $137 \text{ fb}^{-1}$ ; no signal is found and limits are placed on the Higgs boson oblique parameter in the effective field theory framework (EFT) and the model parameters ( $\tan\beta$ ).

NODE=S015CH;LINKAGE=L

<sup>2</sup> AABOUD 19AA search for BSM physics at 13 TeV with  $3.2 \text{ fb}^{-1}$  in  $> 10^5$  regions of  $> 700$  event classes; no significant signal found.

NODE=S015CH;LINKAGE=J

<sup>3</sup> AABOUD 19Q search for single top+MET events at 13 TeV with  $36.1 \text{ fb}^{-1}$  of data; no signal found and limits set in  $\sigma$  or coupling vs. mass plane for variety of simplified models including DM and vector-like top quark  $T$ .

NODE=S015CH;LINKAGE=K

<sup>4</sup> AABOUD 17D search for  $W W jj, W Z jj$  in  $pp$  collisions at 8 TeV with  $3.2 \text{ fb}^{-1}$ ; set limits on anomalous couplings.

NODE=S015CH;LINKAGE=G

- <sup>5</sup> AABOUD 17L search for the pair production of heavy vector-like  $T$  quarks in the  $Z(\rightarrow \nu\nu)tX$  final state. NODE=S015CH;LINKAGE=F
- <sup>6</sup> SIRUNYAN 17B search for vector-like quark  $pp \rightarrow TX \rightarrow tHX$  in  $2.3 \text{ fb}^{-1}$  at 13 TeV; no signal seen; limits placed. NODE=S015CH;LINKAGE=C
- <sup>7</sup> SIRUNYAN 17C search for vector-like quark  $pp \rightarrow TX \rightarrow Z + (t \text{ or } b)$  in  $2.3 \text{ fb}^{-1}$  at 13 TeV; no signal seen; limits placed. NODE=S015CH;LINKAGE=H
- <sup>8</sup> SIRUNYAN 17J search for  $pp \rightarrow X_{5/3}X_{5/3} \rightarrow tWtW$  with  $2.3 \text{ fb}^{-1}$  at 13 TeV. No signal seen:  $m(X) > 1020$  (990) GeV for RH (LH) new charge 5/3 quark. NODE=S015CH;LINKAGE=I
- <sup>9</sup> AAIJ 15BD search for production of long-lived particles in  $pp$  collisions at  $E_{\text{cm}} = 7$  and 8 TeV. See their Table 6 for cross section limits. NODE=S015CH;LINKAGE=E
- <sup>10</sup> AAD 13AH search for production of long-lived particles with  $|q|=(2-6)e$  in  $pp$  collisions at  $E_{\text{cm}} = 7$  TeV with  $4.4 \text{ fb}^{-1}$ . See their Fig. 8 for cross section limits. NODE=S015CH;LINKAGE=DA
- <sup>11</sup> AAD 11I search for production of highly ionizing massive particles in  $pp$  collisions at  $E_{\text{cm}} = 7$  TeV with  $L = 3.1 \text{ pb}^{-1}$ . See their Table 5 for similar limits for  $|q| = 6e$  and  $17e$ , Table 6 for limits on pair production cross section. NODE=S015CH;LINKAGE=AD
- <sup>12</sup> AALTONEN 09Z search for long-lived charged particles in  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96$  TeV with  $L = 1.0 \text{ fb}^{-1}$ . The limits are on production cross section for a particle of mass above 100 GeV in the region  $|\eta| \lesssim 0.7$ ,  $p_T > 40$  GeV, and  $0.4 < \beta < 1.0$ . NODE=S015CH;LINKAGE=AA
- <sup>13</sup> Limit for weakly interacting charge-1 particle. NODE=S015CH;LINKAGE=AL
- <sup>14</sup> Limit for up-quark like particle. NODE=S015CH;LINKAGE=AT
- <sup>15</sup> ABAZOV 09M search for pair production of long-lived charged particles in  $p\bar{p}$  collisions at  $E_{\text{cm}} = 1.96$  TeV with  $L = 1.1 \text{ fb}^{-1}$ . Limit on the cross section of (0.31–0.04) pb (95% CL) is given for the mass range of 60–300 GeV, assuming the kinematics of stau pair production. NODE=S015CH;LINKAGE=AZ
- <sup>16</sup> AKTAS 04C look for charged particle photoproduction at HERA with mean c.m. energy of 200 GeV. NODE=S015CH;LINKAGE=AK
- <sup>17</sup> ABE 92J look for pair production of unit-charged particles which leave detector before decaying. Limit shown here is for  $m=50$  GeV. See their Fig. 5 for different charges and stronger limits for higher mass. NODE=S015CH;LINKAGE=D
- <sup>18</sup> CARROLL 78 look for neutral,  $S = -2$  dihyperon resonance in  $pp \rightarrow 2K^+X$ . Cross section varies within above limits over mass range and  $p_{\text{lab}} = 5.1\text{--}5.9 \text{ GeV}/c$ . NODE=S015CH;LINKAGE=B
- <sup>19</sup> LEIPUNER 73 is an NAL 300 GeV  $p$  experiment. Would have detected particles with lifetime greater than 200 ns. NODE=S015CH;LINKAGE=A

### Heavy Particle Production Differential Cross Section

VALUE ( $\text{cm}^2\text{sr}^{-1}\text{GeV}^{-1}$ )	CL%	DOCUMENT ID	TECN	CHG	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●					
$<2.6 \times 10^{-36}$	90	1 BALDIN	76	CNTR	$Q=1, m=2.1\text{--}9.4 \text{ GeV}$
$<2.2 \times 10^{-33}$	90	2 ALBROW	75	SPEC	$Q=\pm 1, m=4\text{--}15 \text{ GeV}$
$<1.1 \times 10^{-33}$	90	2 ALBROW	75	SPEC	$Q=\pm 2, m=6\text{--}27 \text{ GeV}$
$<8. \times 10^{-35}$	90	3 JOVANO...	75	CNTR	$m=15\text{--}26 \text{ GeV}$
$<1.5 \times 10^{-34}$	90	3 JOVANO...	75	CNTR	$Q=\pm 2, m=3\text{--}10 \text{ GeV}$
$<6. \times 10^{-35}$	90	3 JOVANO...	75	CNTR	$Q=\pm 2, m=10\text{--}26 \text{ GeV}$
$<1. \times 10^{-31}$	90	4 APPEL	74	CNTR	$m=3.2\text{--}7.2 \text{ GeV}$
$<5.8 \times 10^{-34}$	90	5 ALPER	73	SPEC	$m=1.5\text{--}24 \text{ GeV}$
$<1.2 \times 10^{-35}$	90	6 ANTIPOV	71B	CNTR	$Q=-, m=2.2\text{--}2.8$
$<2.4 \times 10^{-35}$	90	7 ANTIPOV	71C	CNTR	$Q=-, m=1.2\text{--}1.7,$ $2.1\text{--}4$
$<2.4 \times 10^{-35}$	90	BINON	69	CNTR	$Q=-, m=1\text{--}1.8 \text{ GeV}$
$<1.5 \times 10^{-36}$		8 DORFAN	65	CNTR	Be target $m=3\text{--}7 \text{ GeV}$
$<3.0 \times 10^{-36}$		8 DORFAN	65	CNTR	Fe target $m=3\text{--}7 \text{ GeV}$

- <sup>1</sup> BALDIN 76 is a 70 GeV Serpukhov experiment. Value is per Al nucleus at  $\theta = 0$ . For other charges in range  $-0.5$  to  $-3.0$ , CL = 90% limit is  $(2.6 \times 10^{-36})/|(charge)|$  for mass range  $(2.1\text{--}9.4 \text{ GeV}) \times |(charge)|$ . Assumes stable particle interacting with matter as do antiprotons. NODE=S015D;LINKAGE=H
- <sup>2</sup> ALBROW 75 is a CERN ISR experiment with  $E_{\text{cm}} = 53 \text{ GeV}$ .  $\theta = 40 \text{ mr}$ . See figure 5 for mass ranges up to 35 GeV. NODE=S015D;LINKAGE=F
- <sup>3</sup> JOVANOVIICH 75 is a CERN ISR 26+26 and 15+15 GeV  $pp$  experiment. Figure 4 covers ranges  $Q = 1/3$  to 2 and  $m = 3$  to 26 GeV. Value is per GeV momentum. NODE=S015D;LINKAGE=G
- <sup>4</sup> APPEL 74 is NAL 300 GeV  $pW$  experiment. Studies forward production of heavy (up to 24 GeV) charged particles with momenta 24–200 GeV ( $-charge$ ) and 40–150 GeV ( $+charge$ ). Above typical value is for 75 GeV and is per GeV momentum per nucleon. NODE=S015D;LINKAGE=E
- <sup>5</sup> ALPER 73 is CERN ISR 26+26 GeV  $pp$  experiment.  $p > 0.9 \text{ GeV}$ ,  $0.2 < \beta < 0.65$ . NODE=S015D;LINKAGE=D
- <sup>6</sup> ANTIPOV 71B is from same 70 GeV  $p$  experiment as ANTIPOV 71C and BINON 69. NODE=S015D;LINKAGE=C
- <sup>7</sup> ANTIPOV 71C limit inferred from flux ratio. 70 GeV  $p$  experiment. NODE=S015D;LINKAGE=B
- <sup>8</sup> DORFAN 65 is a 30 GeV/ $c$   $p$  experiment at BNL. Units are per GeV momentum per nucleus. NODE=S015D;LINKAGE=A

NODE=S015D  
NODE=S015D

OCCUR=2

OCCUR=2

OCCUR=3

OCCUR=2

**Long-Lived Heavy Particle Invariant Cross Section**

VALUE ( $\text{cm}^2/\text{GeV}^2/N$ )	CL%	DOCUMENT ID	TECN	CHG	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●					
$< 5\text{--}700 \times 10^{-35}$	90	<sup>1</sup> BERNSTEIN	88	CNTR	
$< 5\text{--}700 \times 10^{-37}$	90	<sup>1</sup> BERNSTEIN	88	CNTR	
$< 2.5 \times 10^{-36}$	90	<sup>2</sup> THRON	85	CNTR -	$Q=1, m=4\text{--}12$ GeV
$< 1. \times 10^{-35}$	90	<sup>2</sup> THRON	85	CNTR +	$Q=1, m=4\text{--}12$ GeV
$< 6. \times 10^{-33}$	90	<sup>3</sup> ARMITAGE	79	SPEC	$m=1.87$ GeV
$< 1.5 \times 10^{-33}$	90	<sup>3</sup> ARMITAGE	79	SPEC	$m=1.5\text{--}3.0$ GeV
		<sup>4</sup> BOZZOLI	79	CNTR $\pm$	$Q = (2/3, 1, 4/3, 2)$
$< 1.1 \times 10^{-37}$	90	<sup>5</sup> CUTTS	78	CNTR	$m=4\text{--}10$ GeV
$< 3.0 \times 10^{-37}$	90	<sup>6</sup> VIDAL	78	CNTR	$m=4.5\text{--}6$ GeV

NODE=S015ICH  
NODE=S015ICH

OCCUR=2

OCCUR=2

OCCUR=2

NODE=S015ICH;LINKAGE=F

NODE=S015ICH;LINKAGE=E

NODE=S015ICH;LINKAGE=C

NODE=S015ICH;LINKAGE=D

NODE=S015ICH;LINKAGE=A

NODE=S015ICH;LINKAGE=B

<sup>1</sup> BERNSTEIN 88 limits apply at  $x = 0.2$  and  $p_T = 0$ . Mass and lifetime dependence of limits are shown in the regions:  $m = 1.5\text{--}7.5$  GeV and  $\tau = 10^{-8}\text{--}2 \times 10^{-6}$  s. First number is for hadrons; second is for weakly interacting particles.

<sup>2</sup> THRON 85 is FNAL 400 GeV proton experiment. Mass determined from measured velocity and momentum. Limits are for  $\tau > 3 \times 10^{-9}$  s.

<sup>3</sup> ARMITAGE 79 is CERN-ISR experiment at  $E_{\text{cm}} = 53$  GeV. Value is for  $x = 0.1$  and  $p_T = 0.15$ . Observed particles at  $m = 1.87$  GeV are found all consistent with being antideuterons.

<sup>4</sup> BOZZOLI 79 is CERN-SPS 200 GeV  $pN$  experiment. Looks for particle with  $\tau$  larger than  $10^{-8}$  s. See their figure 11–18 for production cross-section upper limits vs mass.

<sup>5</sup> CUTTS 78 is  $p\text{Be}$  experiment at FNAL sensitive to particles of  $\tau > 5 \times 10^{-8}$  s. Value is for  $-0.3 < x < 0$  and  $p_T = 0.175$ .

<sup>6</sup> VIDAL 78 is FNAL 400 GeV proton experiment. Value is for  $x = 0$  and  $p_T = 0$ . Puts lifetime limit of  $< 5 \times 10^{-8}$  s on particle in this mass range.

**Long-Lived Heavy Particle Production  
( $\sigma(\text{Heavy Particle}) / \sigma(\pi)$ )**

VALUE	EVTS	DOCUMENT ID	TECN	CHG	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●					
$< 10^{-8}$		<sup>1</sup> NAKAMURA	89	SPEC $\pm$	$Q = (-5/3, \pm 2)$
	0	<sup>2</sup> BUSSIÈRE	80	CNTR $\pm$	$Q = (2/3, 1, 4/3, 2)$

NODE=S015RPI

NODE=S015RPI

NODE=S015RPI;LINKAGE=B

NODE=S015RPI;LINKAGE=A

<sup>1</sup> NAKAMURA 89 is KEK experiment with 12 GeV protons on Pt target. The limit applies for mass  $\lesssim 1.6$  GeV and lifetime  $\gtrsim 10^{-7}$  s.

<sup>2</sup> BUSSIÈRE 80 is CERN-SPS experiment with 200–240 GeV protons on Be and Al target. See their figures 6 and 7 for cross-section ratio vs mass.

**Production and Capture of Long-Lived Massive Particles**

VALUE ( $10^{-36} \text{ cm}^2$ )	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
$< 20$ to 800	<sup>1</sup> ALEKSEEV	76	ELEC $\tau=5$ ms to 1 day
$< 200$ to 2000	<sup>1</sup> ALEKSEEV	76B	ELEC $\tau=100$ ms to 1 day
$< 1.4$ to 9	<sup>2</sup> FRANKEL	75	CNTR $\tau=50$ ms to 10 hours
$< 0.1$ to 9	<sup>3</sup> FRANKEL	74	CNTR $\tau=1$ to 1000 hours

NODE=S015CA  
NODE=S015CA

NODE=S015CA;LINKAGE=C

NODE=S015CA;LINKAGE=B

NODE=S015CA;LINKAGE=A

<sup>1</sup> ALEKSEEV 76 and ALEKSEEV 76B are 61–70 GeV  $p$  Serpukhov experiment. Cross section is per Pb nucleus.

<sup>2</sup> FRANKEL 75 is extension of FRANKEL 74.

<sup>3</sup> FRANKEL 74 looks for particles produced in thick Al targets by 300–400 GeV/ $c$  protons.

**Long-Lived Particle (LLP) Search at Hadron Collisions**

Limits are for cross section times branching ratio.

VALUE (pb/nucleon)	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●			
	<sup>1</sup> AAD	20D	ATLS $pp \rightarrow \text{LLPs}$ at 13 TeV
	<sup>2</sup> AAD	20J	ATLS scalar boson decay to LLPs
	<sup>3</sup> AAD	20M	ATLS LLP top squark decay to $\mu$
	<sup>4</sup> AAD	20P	ATLS LLP dark photon search
	<sup>5</sup> AAIJ	20AL	LHCB $pp$ dimuon resonance
	<sup>6</sup> BALL	20	LLP milli-charged particles at LHC
	<sup>7</sup> AABOUD	19AE	ATLS $pp$ at 13 TeV
	<sup>8</sup> AABOUD	19AK	ATLS $pp \rightarrow \Phi \rightarrow ZZ_d$
	<sup>9</sup> AABOUD	19AM	ATLS DY multi-charged LLP production
	<sup>10</sup> AABOUD	19AO	ATLS LLP via displaced jets

NODE=S015XL

NODE=S015XL

NODE=S015XL

	11 AABOUD	19AT ATLS	heavy, charged LLPs	
	12 AABOUD	19G ATLS	LLP decay to $\mu^+\mu^-$	
	13 SIRUNYAN	19BH CMS	LLP via displaced jets	
	14 SIRUNYAN	19BT CMS	LLP via displaced jets+MET	
	15 SIRUNYAN	19CA CMS	LLP $\rightarrow \gamma$ search	
	16 SIRUNYAN	19Q CMS	$pp \rightarrow j +$ displaced dark quark jet	
	17 SIRUNYAN	18AWCMS	Long-lived particle search	
	18 AAIJ	16AR LHCb	$H \rightarrow XX$ LLPs	
	19 KHACHATRYAN	16BWCMS	direct production: HSCPs	
< 2 at 90%CL	20 BADIER	86 BDMP	$\tau = (0.05-1.) \times 10^{-8}s$	
1	AAD 20D	search for opposite-sign dileptons originating from long-lived particles in $pp$ collisions at 13 TeV with $32.8 \text{ fb}^{-1}$ ; limits placed in squark cross section vs. $c\tau$ plane for RPV SUSY.		NODE=S015XL;LINKAGE=N
2	AAD 20J	search for scalar boson decay to two long-lived particles; no signal; limits placed in BF vs $c\tau$ plane for various mass hypotheses. This search is also combined with other ATLAS displaced-jet searches.		NODE=S015XL;LINKAGE=Q
3	AAD 20M	search for long-lived top-squarks decay to $\mu$ and hadrons; no signal; limits placed in cross section vs. mass and mass vs. lifetime planes .		NODE=S015XL;LINKAGE=R
4	AAD 20P	search for long-lived dark photons produced from the decay of a scalar boson, with each dark photon decaying into displaced collimated leptons or light hadrons at 13 TeV with $36 \text{ fb}^{-1}$ ; no signal; limits placed in $\sigma \cdot \text{BF}$ vs. $c\tau$ and other planes.		NODE=S015XL;LINKAGE=S
5	AAIJ 20AL	search for long-lived $X \rightarrow \mu^+\mu^-$ decays in $5.1 \text{ fb}^{-1}$ of LHCb data at 13 TeV; no signal; limits placed on $m(X)$ up to 3 GeV depending on kinetic mixing.		NODE=S015XL;LINKAGE=T
6	BALL 20	search for long-lived milli-charged particles produced at LHC; limits placed in charge vs. mass plane (Fig. 8).		NODE=S015XL;LINKAGE=P
7	AABOUD 19AE	search for long-lived particles via displaced jets using $10.8 \text{ fb}^{-1}$ or $33.0 \text{ fb}^{-1}$ data (depending on a trigger) at 13 TeV; no signal found and limits set in branching ratio vs. decay length plane.		NODE=S015XL;LINKAGE=H
8	AABOUD 19AK	searches for long-lived particle $Z_d$ via $pp \rightarrow \Phi \rightarrow ZZ_d$ at 13 TeV with $36.1 \text{ fb}^{-1}$ ; no signal found and limits set in $\sigma \times \text{BR}$ vs. lifetime plane for simplified model.		NODE=S015XL;LINKAGE=I
9	AABOUD 19AM	search for Drell-Yan (DY) production of long-lived multi-charge particles at 13 TeV with $36.1 \text{ fb}^{-1}$ of data; no signal found and exclude $50 \text{ GeV} < m(\text{LLMCP}) < 980-1220 \text{ GeV}$ for electric charge $ q  = (2-7)e$ .		NODE=S015XL;LINKAGE=J
10	AABOUD 19AO	search for neutral long-lived particles producing displaced jets at 13 TeV with $36.1 \text{ fb}^{-1}$ of data; no signal found and exclude regions of $\sigma \cdot \text{BR}$ vs. lifetime plane for various models.		NODE=S015XL;LINKAGE=K
11	AABOUD 19AT	search for heavy, charged long-lived particles at 13 TeV with $36.1 \text{ fb}^{-1}$ ; no signal found and upper limits set on masses of various hypothetical particles.		NODE=S015XL;LINKAGE=L
12	AABOUD 19G	search for long-lived particle with decay to $\mu^+\mu^-$ at 13 TeV with $32.9 \text{ fb}^{-1}$ ; no signal found and limits set in combinations of lifetime, mass and coupling planes for various simplified models.		NODE=S015XL;LINKAGE=M
13	SIRUNYAN 19BH	search for long-lived SUSY particles via displaced jets at 13 TeV with $35.9 \text{ fb}^{-1}$ ; no signal found and limits placed in mass vs lifetime plane for various hypothetical models.		NODE=S015XL;LINKAGE=E
14	SIRUNYAN 19BT	search for displaced jet(s)+ $\cancel{E}_T$ at 13 TeV with $137 \text{ fb}^{-1}$ ; no signal found and limits placed in mass vs lifetime plane for gauge mediated SUSY breaking models.		NODE=S015XL;LINKAGE=F
15	SIRUNYAN 19CA	search for gluino/squark decay to long-lived neutralino, decay to $\gamma$ in GMSB; no signal, limits placed in $m(\chi)$ vs. lifetime plane for SPS8 GMSB benchmark point .		NODE=S015XL;LINKAGE=O
16	SIRUNYAN 19Q	search for $pp \rightarrow j +$ displaced jet via dark quark with 13 TeV at $16.1 \text{ fb}^{-1}$ ; no signal found and limits set in mass vs lifetime plane for dark quark/dark pion model.		NODE=S015XL;LINKAGE=G
17	SIRUNYAN 18AW	search for very long lived particles (LLPs) decaying hadronically or to $\mu\bar{\mu}$ in CMS detector; none seen/limits set on lifetime vs. cross section.		NODE=S015XL;LINKAGE=D
18	AAIJ 16AR	search for long lived particles from $H \rightarrow XX$ with displaced $X$ decay vertex using $0.62 \text{ fb}^{-1}$ at 7 TeV; limits set in Fig. 7.		NODE=S015XL;LINKAGE=B
19	KHACHATRYAN 16BW	search for heavy stable charged particles via ToF with $2.5 \text{ fb}^{-1}$ at 13 TeV; require stable $m(\text{gluinoball}) > 1610 \text{ GeV}$ .		NODE=S015XL;LINKAGE=C
20	BADIER 86	looked for long-lived particles at 300 GeV $\pi^-$ beam dump. The limit applies for nonstrongly interacting neutral or charged particles with mass $> 2 \text{ GeV}$ . The limit applies for particle modes, $\mu^+\pi^-$ , $\mu^+\mu^-$ , $\pi^+\pi^-X$ , $\pi^+\pi^-\pi^\pm$ etc. See their figure 5 for the contours of limits in the mass- $\tau$ plane for each mode.		NODE=S015XL;LINKAGE=A

### Long-Lived Heavy Particle Cross Section

VALUE (pb/sr)	CL%	DOCUMENT ID	TECN	COMMENT
<34	95	1 RAM	94 SPEC	$1015 < m_{X^{++}} < 1085 \text{ MeV}$
<75	95	1 RAM	94 SPEC	$920 < m_{X^{++}} < 1025 \text{ MeV}$

• • • We do not use the following data for averages, fits, limits, etc. • • •

NODE=S015DCC  
NODE=S015DCC

OCCUR=2

<sup>1</sup> RAM 94 search for a long-lived doubly-charged fermion  $X^{++}$  with mass between  $m_N$  and  $m_N + m_\pi$  and baryon number +1 in the reaction  $pp \rightarrow X^{++} n$ . No candidate is found. The limit is for the cross section at  $15^\circ$  scattering angle at 460 MeV incident energy and applies for  $\tau(X^{++}) \gg 0.1 \mu\text{s}$ .

NODE=S015DCC;LINKAGE=A

## LIMITS ON CHARGED PARTICLES IN COSMIC RAYS

NODE=S015435

### Heavy Particle Flux in Cosmic Rays

NODE=S015F  
NODE=S015F

VALUE ( $\text{cm}^{-2}\text{sr}^{-1}\text{s}^{-1}$ )	CL%	EVTs	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●					
< 1	$\times 10^{-8}$	90	<sup>1</sup> ALVIS	18 MAJD	Fractionally charged
< 1.7	$\times 10^{-11}$	99	<sup>2</sup> AGNESE	15 CDM2	$Q = 1/6$
$\sim 6$	$\times 10^{-9}$	2	<sup>3</sup> SAITO	90	$Q \simeq 14, m \simeq 370m_p$
< 1.4	$\times 10^{-12}$	90	<sup>4</sup> MINCER	85 CALO	$m \geq 1 \text{ TeV}$
< 1.7	$\times 10^{-11}$	99	<sup>5</sup> SAKUYAMA	83B PLAS	$m \sim 1 \text{ TeV}$
< 1.	$\times 10^{-9}$	90	<sup>6</sup> BHAT	82 CC	
2.	$\times 10^{-9}$	3	<sup>7</sup> MARINI	82 CNTR	$Q = 1, m \sim 4.5m_p$
		3	<sup>8</sup> YOCK	81 SPRK	$Q = 1, m \sim 4.5m_p$
		3	<sup>8</sup> YOCK	81 SPRK	Fractionally charged
3.0	$\times 10^{-9}$	3	<sup>9</sup> YOCK	80 SPRK	$m \sim 4.5 m_p$
$(4 \pm 1) \times 10^{-11}$		3	GOODMAN	79 ELEC	$m \geq 5 \text{ GeV}$
< 1.3	$\times 10^{-9}$	90	<sup>10</sup> BHAT	78 CNTR	$m > 1 \text{ GeV}$
< 1.0	$\times 10^{-9}$	0	BRIATORE	76 ELEC	
< 7.	$\times 10^{-10}$	90	YOCK	75 ELEC	$Q > 7e \text{ or } < -7e$
> 6.	$\times 10^{-9}$	5	<sup>11</sup> YOCK	74 CNTR	$m > 6 \text{ GeV}$
< 3.0	$\times 10^{-8}$	0	DARDO	72 CNTR	
< 1.5	$\times 10^{-9}$	0	TONWAR	72 CNTR	$m > 10 \text{ GeV}$
< 3.0	$\times 10^{-10}$	0	BJORNBOE	68 CNTR	$m > 5 \text{ GeV}$
< 5.0	$\times 10^{-11}$	90	JONES	67 ELEC	$m = 5-15 \text{ GeV}$

OCCUR=2

<sup>1</sup> ALVIS 18 search for fractional charged flux of cosmic matter at Majorana demonstrator; no signal observed and limits are set on the flux of lightly ionizing particles for charge as low as  $e/1000$ .

NODE=S015F;LINKAGE=J

<sup>2</sup> See AGNESE 15 Fig. 6 for limits extending down to  $Q = 1/200$ .

NODE=S015F;LINKAGE=D

<sup>3</sup> SAITO 90 candidates carry about 450 MeV/nucleon. Cannot be accounted for by conventional backgrounds. Consistent with strange quark matter hypothesis.

NODE=S015F;LINKAGE=K

<sup>4</sup> MINCER 85 is high statistics study of calorimeter signals delayed by 20–200 ns. Calibration with AGS beam shows they can be accounted for by rare fluctuations in signals from low-energy hadrons in the shower. Claim that previous delayed signals including BJORNBOE 68, DARDO 72, BHAT 82, SAKUYAMA 83B below may be due to this fake effect.

NODE=S015F;LINKAGE=I

<sup>5</sup> SAKUYAMA 83B analyzed 6000 extended air shower events. Increase of delayed particles and change of lateral distribution above  $10^{17}$  eV may indicate production of very heavy parent at top of atmosphere.

NODE=S015F;LINKAGE=H

<sup>6</sup> BHAT 82 observed 12 events with delay  $> 2. \times 10^{-8}$  s and with more than 40 particles. 1 eV has good hadron shower. However all events are delayed in only one of two detectors in cloud chamber, and could not be due to strongly interacting massive particle.

NODE=S015F;LINKAGE=F

<sup>7</sup> MARINI 82 applied PEP-counter for TOF. Above limit is for velocity = 0.54 of light. Limit is inconsistent with YOCK 80 YOCK 81 events if isotropic dependence on zenith angle is assumed.

NODE=S015F;LINKAGE=G

<sup>8</sup> YOCK 81 saw another 3 events with  $Q = \pm 1$  and  $m$  about  $4.5m_p$  as well as 2 events with  $m > 5.3m_p$ ,  $Q = \pm 0.75 \pm 0.05$  and  $m > 2.8m_p$ ,  $Q = \pm 0.70 \pm 0.05$  and 1 event with  $m = (9.3 \pm 3.)m_p$ ,  $Q = \pm 0.89 \pm 0.06$  as possible heavy candidates.

NODE=S015F;LINKAGE=E

<sup>9</sup> YOCK 80 events are with charge exactly or approximately equal to unity.

NODE=S015F;LINKAGE=C

<sup>10</sup> BHAT 78 is at Kolar gold fields. Limit is for  $\tau > 10^{-6}$  s.

NODE=S015F;LINKAGE=B

<sup>11</sup> YOCK 74 events could be tritons.

NODE=S015F;LINKAGE=A

### Superheavy Particle (Quark Matter) Flux in Cosmic Rays

NODE=S015FQ  
NODE=S015FQ

VALUE ( $\text{cm}^{-2}\text{sr}^{-1}\text{s}^{-1}$ )	CL%	DOCUMENT ID	TECN	COMMENT
● ● ● We do not use the following data for averages, fits, limits, etc. ● ● ●				
< 5	$\times 10^{-16}$	90	<sup>1</sup> ADRIANI	15 PMLA $4 < m < 1.2 \times 10^5 m_p$
< 1.8	$\times 10^{-12}$	90	<sup>2</sup> AMBROSIO	00B MCRO $m > 5 \times 10^{14} \text{ GeV}$
< 1.1	$\times 10^{-14}$	90	<sup>3</sup> ASTONE	93 CNTR $m \geq 1.5 \times 10^{-13} \text{ gram}$
< 2.2	$\times 10^{-14}$	90	<sup>4</sup> AHLEN	92 MCRO $10^{-10} < m < 0.1 \text{ gram}$
< 6.4	$\times 10^{-16}$	90	<sup>5</sup> NAKAMURA	91 PLAS $m > 10^{11} \text{ GeV}$
		90	<sup>6</sup> ORITO	91 PLAS $m > 10^{12} \text{ GeV}$

$<2.0 \times 10^{-11}$	90	7 LIU	88	BOLO	$m > 1.5 \times 10^{-13}$ gram
$<4.7 \times 10^{-12}$	90	8 BARISH	87	CNTR	$1.4 \times 10^8 < m < 10^{12}$ GeV
$<3.2 \times 10^{-11}$	90	9 NAKAMURA	85	CNTR	$m > 1.5 \times 10^{-13}$ gram
$<3.5 \times 10^{-11}$	90	10 ULLMAN	81	CNTR	Planck-mass $10^{19}$ GeV
$<7. \times 10^{-11}$	90	10 ULLMAN	81	CNTR	$m \leq 10^{16}$ GeV

OCCUR=2

<sup>1</sup> ADRIANI 15 search for relatively light quark matter with charge  $Z = 1-8$ . See their Figs. 2 and 3 for flux upper limits.

NODE=S015FQ;LINKAGE=A

<sup>2</sup> AMBROSIO 00B searched for quark matter ("nuclearites") in the velocity range  $(10^{-5}-1)$  c. The listed limit is for  $2 \times 10^{-3}$  c.

NODE=S015FQ;LINKAGE=AM

<sup>3</sup> ASTONE 93 searched for quark matter ("nuclearites") in the velocity range  $(10^{-3}-1)$  c. Their Table 1 gives a compilation of searches for nuclearites.

NODE=S015FQ;LINKAGE=L

<sup>4</sup> AHLEN 92 searched for quark matter ("nuclearites"). The bound applies to velocity  $< 2.5 \times 10^{-3}$  c. See their Fig. 3 for other velocity/c and heavier mass range.

NODE=S015FQ;LINKAGE=M

<sup>5</sup> NAKAMURA 91 searched for quark matter in the velocity range  $(4 \times 10^{-5}-1)$  c.

NODE=S015FQ;LINKAGE=NK

<sup>6</sup> ORITO 91 searched for quark matter. The limit is for the velocity range  $(10^{-4}-10^{-3})$  c.

NODE=S015FQ;LINKAGE=OR

<sup>7</sup> LIU 88 searched for quark matter ("nuclearites") in the velocity range  $(2.5 \times 10^{-3}-1)$  c. A less stringent limit of  $5.8 \times 10^{-11}$  applies for  $(1-2.5) \times 10^{-3}$  c.

NODE=S015FQ;LINKAGE=L8

<sup>8</sup> BARISH 87 searched for quark matter ("nuclearites") in the velocity range  $(2.7 \times 10^{-4}-5 \times 10^{-3})$  c.

NODE=S015FQ;LINKAGE=B7

<sup>9</sup> NAKAMURA 85 at KEK searched for quark-matter. These might be lumps of strange quark matter with roughly equal numbers of  $u, d, s$  quarks. These lumps or nuclearites were assumed to have velocity of  $(10^{-4}-10^{-3})$  c.

NODE=S015FQ;LINKAGE=J

<sup>10</sup> ULLMAN 81 is sensitive for heavy slow singly charge particle reaching earth with vertical velocity 100-350 km/s.

NODE=S015FQ;LINKAGE=D

### Highly Ionizing Particle Flux

VALUE ( $m^{-2}yr^{-1}$ )	CL%	EVTS	DOCUMENT ID	TECN	COMMENT
• • •					We do not use the following data for averages, fits, limits, etc. • • •
<0.4	95	0	KINOSHITA	81B PLAS	$Z/\beta$ 30-100

NODE=S015ION

NODE=S015ION

### SEARCHES FOR BLACK HOLE PRODUCTION

NODE=S015BHP

VALUE	DOCUMENT ID	TECN	COMMENT
• • •			We do not use the following data for averages, fits, limits, etc. • • •
not seen	1 AABOUD	16P ATLS	13 TeV $pp \rightarrow e\mu, e\tau, \mu\tau$
	2 AAD	15AN ATLS	8 TeV $pp \rightarrow$ multijets
	3 AAD	14A ATLS	8 TeV $pp \rightarrow \gamma +$ jet
	4 AAD	14AL ATLS	8 TeV $pp \rightarrow \ell +$ jet
	5 AAD	14C ATLS	8 TeV $pp \rightarrow \ell + (\ell \text{ or jets})$
	6 AAD	13D ATLS	7 TeV $pp \rightarrow 2$ jets
	7 CHATRCHYAN 13A	CMS	7 TeV $pp \rightarrow 2$ jets
	8 CHATRCHYAN 13AD	CMS	8 TeV $pp \rightarrow$ multijets
	9 AAD	12AK ATLS	7 TeV $pp \rightarrow \ell + (\ell \text{ or jets})$
	10 CHATRCHYAN 12W	CMS	7 TeV $pp \rightarrow$ multijets
	11 AAD	11AG ATLS	7 TeV $pp \rightarrow 2$ jets

NODE=S015BHP

<sup>1</sup> AABOUD 16P set limits on quantum BH production in  $n = 6$  ADD or  $n = 1$  RS models.

NODE=S015BHP;LINKAGE=G

<sup>2</sup> AAD 15AN search for black hole or string ball formation followed by its decay to multijet final states, in  $pp$  collisions at  $E_{cm} = 8$  TeV with  $L = 20.3 \text{ fb}^{-1}$ . See their Figs. 6-8 for limits.

NODE=S015BHP;LINKAGE=F

<sup>3</sup> AAD 14A search for quantum black hole formation followed by its decay to a  $\gamma$  and a jet, in  $pp$  collisions at  $E_{cm} = 8$  TeV with  $L = 20 \text{ fb}^{-1}$ . See their Fig. 3 for limits.

NODE=S015BHP;LINKAGE=A

<sup>4</sup> AAD 14AL search for quantum black hole formation followed by its decay to a lepton and a jet, in  $pp$  collisions at  $E_{cm} = 8$  TeV with  $L = 20.3 \text{ fb}^{-1}$ . See their Fig. 2 for limits.

NODE=S015BHP;LINKAGE=C

<sup>5</sup> AAD 14C search for microscopic (semiclassical) black hole formation followed by its decay to final states with a lepton and  $\geq 2$  (leptons or jets), in  $pp$  collisions at  $E_{cm} = 8$  TeV with  $L = 20.3 \text{ fb}^{-1}$ . See their Figures 8-11, Tables 7, 8 for limits.

NODE=S015BHP;LINKAGE=D

<sup>6</sup> AAD 13D search for quantum black hole formation followed by its decay to two jets, in  $pp$  collisions at  $E_{cm} = 7$  TeV with  $L = 4.8 \text{ fb}^{-1}$ . See their Fig. 8 and Table 3 for limits.

NODE=S015BHP;LINKAGE=GA

<sup>7</sup> CHATRCHYAN 13A search for quantum black hole formation followed by its decay to two jets, in  $pp$  collisions at  $E_{cm} = 7$  TeV with  $L = 5 \text{ fb}^{-1}$ . See their Figs. 5 and 6 for limits.

NODE=S015BHP;LINKAGE=CT

<sup>8</sup> CHATRCHYAN 13AD search for microscopic (semiclassical) black hole formation followed by its evaporation to multiparticle final states, in multijet (including  $\gamma, \ell$ ) events in  $pp$  collisions at  $E_{cm} = 8$  TeV with  $L = 12 \text{ fb}^{-1}$ . See their Figs. 5-7 for limits.

NODE=S015BHP;LINKAGE=B

<sup>9</sup> AAD 12AK search for microscopic (semiclassical) black hole formation followed by its decay to final states with a lepton and  $\geq 2$  (leptons or jets), in  $pp$  collisions at  $E_{cm} = 7$  TeV with  $L = 1.04 \text{ fb}^{-1}$ . See their Fig. 4 and 5 for limits.

NODE=S015BHP;LINKAGE=E

- <sup>10</sup> CHATRCHYAN 12W search for microscopic (semiclassical) black hole formation followed by its evaporation to multiparticle final states, in multijet (including  $\gamma$ ,  $\ell$ ) events in  $pp$  collisions at  $E_{cm} = 7$  TeV with  $L = 4.7 \text{ fb}^{-1}$ . See their Figs. 5–8 for limits.
- <sup>11</sup> AAD 11AG search for quantum black hole formation followed by its decay to two jets, in  $pp$  collisions at  $E_{cm} = 7$  TeV with  $L = 36 \text{ pb}^{-1}$ . See their Fig. 11 and Table 4 for limits.

NODE=S015BHP;LINKAGE=CH

NODE=S015BHP;LINKAGE=AD

## REFERENCES FOR Other Particle Searches

NODE=S015

AAD	20AD	PRL 125 131801	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=60682
AAD	20D	PL B801 135114	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=60192
AAD	20J	PR D101 052013	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=60276
AAD	20M	PR D102 032006	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=60348
AAD	20P	EPJ C80 450	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=60437
AAD	20T	JHEP 2003 145	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=60484
AAD	20W	JHEP 2006 151	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=60507
AAJ	20AL	JHEP 2010 156	R. Aaij <i>et al.</i>	(LHCb Collab.)	REFID=60754
AGUILAR-AR...	20B	JHEP 2004 054	A. Aguilar-Arevalo <i>et al.</i>	(CONNIE Collab.)	REFID=60488
BALL	20	PR D102 032002	A.H. Ball <i>et al.</i>	(milliQan)	REFID=60345
FEDDERKE	20	PR D101 115021	M.A. Fedderke, P.W. Graham, S. Rajendran	(STAN+)	REFID=60324
SIRUNYAN	20A	EPJ C80 3	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=60199
SIRUNYAN	20AI	JHEP 2005 033	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=60492
SIRUNYAN	20AY	PL B808 135578	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=60624
SIRUNYAN	20C	EPJ C80 75	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=60222
SIRUNYAN	20N	PL B806 135502	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=60404
SIRUNYAN	20Z	JHEP 2003 051	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=60475
AABOUD	19AA	EPJ C79 120	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=59705
AABOUD	19AE	EPJ C79 481	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=59729
AABOUD	19AJ	PL B795 56	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=59756
AABOUD	19AK	PRL 122 151801	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=59774
AABOUD	19AM	PR D99 052003	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=59840
AABOUD	19AO	PR D99 052005	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=59842
AABOUD	19AT	PR D99 092007	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=59877
AABOUD	19G	PR D99 012001	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=59518
AABOUD	19H	PR D99 012008	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=59600
AABOUD	19Q	JHEP 1905 041	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=59680
AABOUD	19V	JHEP 1905 142	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=59686
ALCANTARA	19	PR D99 103016	E. Alcantara, L.A. Anchordoqui, J.F. Soriano		REFID=59948
SIRUNYAN	19B	PR D99 012005	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=59516
SIRUNYAN	19BH	PR D99 032011	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=59832
SIRUNYAN	19BT	PL B797 134876	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=59936
SIRUNYAN	19CA	PR D100 112003	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=60039
SIRUNYAN	19CD	PRL 123 231803	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=60074
SIRUNYAN	19O	JHEP 1902 074	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=59649
SIRUNYAN	19Q	JHEP 1902 179	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=59653
AABOUD	18AD	PL B779 24	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=58998
AABOUD	18CJ	PR D98 052008	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=59441
AABOUD	18CK	PR D98 092002	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=59470
AABOUD	18CL	PR D98 092005	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=59472
AABOUD	18CM	PR D98 092008	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=59474
AABOUD	18N	PRL 121 081801	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=58866
AAJ	18AJ	PRL 120 061801	R. Aaij <i>et al.</i>	(LHCb Collab.)	REFID=59199
ALBERT	18C	PR D98 123012	A. Albert <i>et al.</i>	(HAWC Collab.)	REFID=59510
ALVIS	18	PRL 120 211804	S.I. Alvis <i>et al.</i>	(MAJORANA Collab.)	REFID=58832
BANERJEE	18	PRL 120 231802	D. Banerjee <i>et al.</i>	(NA64 Collab.)	REFID=58838
BANERJEE	18A	PR D97 072002	D. Banerjee <i>et al.</i>	(NA64 Collab.)	REFID=58916
KILE	18	JHEP 1810 116	J. Kile, J. von Wimmersperg-Toeller	(LISBT)	REFID=59564
MARSICANO	18	PR D98 015031	L. Marsicano <i>et al.</i>		REFID=58967
PORAYKO	18	PR D98 102002	N.K. Porayako <i>et al.</i>	(PPTA Collab.)	REFID=59488
SIRUNYAN	18AW	JHEP 1805 127	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=59101
SIRUNYAN	18BB	JHEP 1806 120	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=59112
SIRUNYAN	18DA	JHEP 1811 042	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=59306
SIRUNYAN	18DD	EPJ C78 789	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=59318
SIRUNYAN	18DJ	JHEP 1809 101	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=59341
SIRUNYAN	18DR	JHEP 1811 161	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=59367
SIRUNYAN	18DU	PR D98 092001	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=59469
SIRUNYAN	18DY	PR D98 112014	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=59504
SIRUNYAN	18ED	JHEP 1811 172	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=59566
AABOUD	17B	PL B765 32	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=57706
AABOUD	17D	PR D95 032001	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=57751
AABOUD	17L	JHEP 1708 052	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=57829
AAJ	17BR	EPJ C77 812	R. Aaij <i>et al.</i>	(LHCb Collab.)	REFID=58366
ABLIKIM	17AA	PL B774 252	M. Ablikim <i>et al.</i>	(BESIII Collab.)	REFID=58253
KHACHATRY...	17D	JHEP 1701 076	V. Khachatryan <i>et al.</i>	(CMS Collab.)	REFID=57750
KHACHATRY...	17W	PL B769 520	V. Khachatryan <i>et al.</i>	(CMS Collab.)	REFID=57899
KHACHATRY...	17Y	PL B770 257	V. Khachatryan <i>et al.</i>	(CMS Collab.)	REFID=57904
SIRUNYAN	17B	JHEP 1704 136	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=57808
SIRUNYAN	17C	JHEP 1705 029	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=57812
SIRUNYAN	17F	JHEP 1707 013	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=57820
SIRUNYAN	17J	JHEP 1708 073	A.M. Sirunyan <i>et al.</i>	(CMS Collab.)	REFID=57831
ZANG	17	PL B773 159	X. Zang, G.A. Miller	(WASH)	REFID=59311
AABOUD	16	PL B759 229	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=57233
AABOUD	16P	EPJ C76 541	M. Aaboud <i>et al.</i>	(ATLAS Collab.)	REFID=57558
AAD	16AI	JHEP 1603 041	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=57322
AAD	16N	JHEP 1603 026	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=57168
AAD	16O	PL B760 520	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=57169
AAD	16R	PL B755 285	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=57172
AAD	16S	PL B754 302	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=57206
AAJ	16AR	EPJ C76 664	R. Aaij <i>et al.</i>	(LHCb Collab.)	REFID=57684
KHACHATRY...	16BW	PR D94 112004	V. Khachatryan <i>et al.</i>	(CMS Collab.)	REFID=57620
KHACHATRY...	16K	PRL 116 071801	V. Khachatryan <i>et al.</i>	(CMS Collab.)	REFID=57181
KHACHATRY...	16L	PRL 117 031802	V. Khachatryan <i>et al.</i>	(CMS Collab.)	REFID=57195
KHACHATRY...	16M	PRL 117 051802	V. Khachatryan <i>et al.</i>	(CMS Collab.)	REFID=57196
KRASZNAHO...	16	PRL 116 042501	A.J. Krasznahorkay <i>et al.</i>	(HINR, ANIK+)	REFID=59302
AAD	15AN	JHEP 1507 032	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=56644
AAD	15AT	EPJ C75 79	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=56661

AAD	15BJ	EPJ C75 362	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=56677
AAIJ	15BD	EPJ C75 595	R. Aaij <i>et al.</i>	(LHCb Collab.)	REFID=57032
ADRIANI	15	PRL 115 111101	O. Adriani <i>et al.</i>	(PAMELA Collab.)	REFID=56947
AGNESE	15	PRL 114 111302	R. Agnese <i>et al.</i>	(CDMS Collab.)	REFID=56445
KHACHATRY...	15F	PRL 114 101801	V. Khachatryan <i>et al.</i>	(CMS Collab.)	REFID=56446
LEES	15E	PRL 114 171801	J.P. Lees <i>et al.</i>	(BABAR Collab.)	REFID=56467
AAD	14A	PL B728 562	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=55629
AAD	14AL	PRL 112 091804	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=56056
AAD	14C	JHEP 1408 103	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=55715
AALTONEN	14J	PR D89 092001	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=56030
AAD	13A	PL B718 860	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=54789
AAD	13AH	PL B722 305	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=55079
AAD	13C	PRL 110 011802	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=54791
AAD	13D	JHEP 1301 029	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=54792
AALTONEN	13I	PR D88 031103	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=55173
AALTONEN	13R	PRL 111 031802	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=55220
CHATRCHYAN	13	PL B718 815	S. Chatrchyan <i>et al.</i>	(CMS Collab.)	REFID=54769
CHATRCHYAN	13A	JHEP 1301 013	S. Chatrchyan <i>et al.</i>	(CMS Collab.)	REFID=54770
CHATRCHYAN	13AB	JHEP 1307 122	S. Chatrchyan <i>et al.</i>	(CMS Collab.)	REFID=55042
CHATRCHYAN	13AD	JHEP 1307 178	S. Chatrchyan <i>et al.</i>	(CMS Collab.)	REFID=55045
CHATRCHYAN	13AR	PR D87 092008	S. Chatrchyan <i>et al.</i>	(CMS Collab.)	REFID=55151
AAD	12AK	PL B716 122	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=54200
AAD	12C	PRL 108 041805	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=54080
AAD	12S	PL B708 37	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=54152
AALTONEN	12M	PRL 108 211804	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=54242
CHATRCHYAN	12AP	JHEP 1209 094	S. Chatrchyan <i>et al.</i>	(CMS Collab.)	REFID=54572
CHATRCHYAN	12BL	JHEP 1212 015	S. Chatrchyan <i>et al.</i>	(CMS Collab.)	REFID=54776
CHATRCHYAN	12Q	PL B716 260	S. Chatrchyan <i>et al.</i>	(CMS Collab.)	REFID=54184
CHATRCHYAN	12T	PRL 108 261803	S. Chatrchyan <i>et al.</i>	(CMS Collab.)	REFID=54251
CHATRCHYAN	12W	JHEP 1204 061	S. Chatrchyan <i>et al.</i>	(CMS Collab.)	REFID=54459
AAD	11AG	NJP 13 053044	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=54009
AAD	11I	PL B698 353	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=16565
AAD	11S	PL B705 294	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=53851
AALTONEN	11AF	PRL 107 181801	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=53833
AALTONEN	11M	PRL 106 171801	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=16445
ABAZOV	11I	PRL 107 011804	V.M. Abazov <i>et al.</i>	(D0 Collab.)	REFID=16475
CHATRCHYAN	11C	JHEP 1106 026	S. Chatrchyan <i>et al.</i>	(CMS Collab.)	REFID=16351
CHATRCHYAN	11U	PRL 107 201804	S. Chatrchyan <i>et al.</i>	(CMS Collab.)	REFID=53840
AAD	10	PRL 105 161801	G. Aad <i>et al.</i>	(ATLAS Collab.)	REFID=53477
AALTONEN	10AF	PR D82 052005	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=53618
KHACHATRY...	10	PRL 105 211801	V. Khachatryan <i>et al.</i>	(CMS Collab.)	REFID=53465
Also		PRL 106 029902	V. Khachatryan <i>et al.</i>	(CMS Collab.)	REFID=53629
AALTONEN	09AF	PR D80 011102	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=52948
AALTONEN	09G	PR D79 052004	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=52801
AALTONEN	09Z	PRL 103 021802	T. Aaltonen <i>et al.</i>	(CDF Collab.)	REFID=52931
ABAZOV	09M	PRL 102 161802	V.M. Abazov <i>et al.</i>	(D0 Collab.)	REFID=52866
AKTAS	04C	EPJ C36 413	A. Aktas <i>et al.</i>	(H1 Collab.)	REFID=50148
JAVORSEK	02	PR D65 072003	D. Javorsek II <i>et al.</i>		REFID=48882
JAVORSEK	01	PR D64 012005	D. Javorsek II <i>et al.</i>		REFID=48180
JAVORSEK	01B	PRL 87 231804	D. Javorsek II <i>et al.</i>		REFID=48439
ABBIENDI	00D	EPJ C13 197	G. Abbiendi <i>et al.</i>	(OPAL Collab.)	REFID=47464
AMBROSIO	00B	EPJ C13 453	M. Ambrosio <i>et al.</i>	(MACRO Collab.)	REFID=47625
ABE	99F	PRL 82 2038	F. Abe <i>et al.</i>	(CDF Collab.)	REFID=46728
ACKERSTAFF	98P	PL B433 195	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)	REFID=46077
ABE	97G	PR D55 5263	F. Abe <i>et al.</i>	(CDF Collab.)	REFID=45343
ABREU	97D	PL B396 315	P. Abreu <i>et al.</i>	(DELPHI Collab.)	REFID=45316
ACKERSTAFF	97B	PL B391 210	K. Ackerstaff <i>et al.</i>	(OPAL Collab.)	REFID=45244
ADAMS	97B	PRL 79 4083	J. Adams <i>et al.</i>	(FNAL KTeV Collab.)	REFID=45722
BARATE	97K	PL B405 379	R. Barate <i>et al.</i>	(ALEPH Collab.)	REFID=45551
AKERS	95R	ZPHY C67 203	R. Akers <i>et al.</i>	(OPAL Collab.)	REFID=44370
GALLAS	95	PR D52 6	E. Gallas <i>et al.</i>	(MSU, FNAL, MIT, FLOR)	REFID=44291
RAM	94	PR D49 3120	S. Ram <i>et al.</i>	(TELA, TRIU)	REFID=43855
ABE	93G	PRL 71 2542	F. Abe <i>et al.</i>	(CDF Collab.)	REFID=43512
ASTONE	93	PR D47 4770	P. Astone <i>et al.</i>	(ROMA, ROMAI, CATA, FRAS)	REFID=43329
BUSKULIC	93C	PL B303 198	D. Buskulic <i>et al.</i>	(ALEPH Collab.)	REFID=43295
YAMAGATA	93	PR D47 1231	T. Yamagata, Y. Takamori, H. Utsunomiya	(KONAN)	REFID=43102
ABE	92J	PR D46 1889	F. Abe <i>et al.</i>	(CDF Collab.)	REFID=42100
AHLEN	92	PRL 69 1860	S.P. Ahlen <i>et al.</i>	(MACRO Collab.)	REFID=42185
VERKERK	92	PRL 68 1116	P. Verkerk <i>et al.</i>	(ENSP, SACL, PAST)	REFID=41964
AKESSON	91	ZPHY C52 219	T. Akesson <i>et al.</i>	(HELIOS Collab.)	REFID=41739
NAKAMURA	91	PL B263 529	S. Nakamura <i>et al.</i>		REFID=48079
ORITO	91	PRL 66 1951	S. Orito <i>et al.</i>	(ICEPP, WASCR, NIHO, ICRR)	REFID=41478
ADACHI	90C	PL B244 352	I. Adachi <i>et al.</i>	(TOPAZ Collab.)	REFID=41322
ADACHI	90E	PL B249 336	I. Adachi <i>et al.</i>	(TOPAZ Collab.)	REFID=41410
AKRAWY	90O	PL B252 290	M.Z. Akrawy <i>et al.</i>	(OPAL Collab.)	REFID=41425
HEMMICK	90	PR D41 2074	T.K. Hemmick <i>et al.</i>	(ROCH, MICH, OHIO+)	REFID=41245
SAITO	90	PRL 65 2094	T. Saito <i>et al.</i>	(ICRR, KOBE)	REFID=41713
NAKAMURA	89	PR D39 1261	T.T. Nakamura <i>et al.</i>	(KYOT, TMTC)	REFID=40833
NORMAN	89	PR D39 2499	E.B. Norman <i>et al.</i>	(LBL)	REFID=40841
BERNSTEIN	88	PR D37 3103	R.M. Bernstein <i>et al.</i>	(STAN, WISC)	REFID=40673
LIU	88	PRL 61 271	G. Liu, B. Barish		REFID=48116
BARISH	87	PR D36 2641	B.C. Barish, G. Liu, C. Lane	(CIT)	REFID=40495
NORMAN	87	PRL 58 1403	E.B. Norman, S.B. Gazes, D.A. Bennett	(LBL)	REFID=40168
BADIER	86	ZPHY C31 21	J. Badier <i>et al.</i>	(NA3 Collab.)	REFID=10622
MINCER	85	PR D32 541	A. Mincer <i>et al.</i>	(UMD, GMAS, NSF)	REFID=12660
NAKAMURA	85	PL 161B 417	K. Nakamura <i>et al.</i>	(KEK, INUS)	REFID=12661
THRON	85	PR D31 451	J.L. Thron <i>et al.</i>	(YALE, FNAL, IOWA)	REFID=12663
SAKUYAMA	83B	LNC 37 17	H. Sakuyama, N. Suzuki	(MEIS)	REFID=12644
Also		LNC 36 389	H. Sakuyama, K. Watanabe	(MEIS)	REFID=12645
Also		NC 78A 147	H. Sakuyama, K. Watanabe	(MEIS)	REFID=12646
Also		NC 6C 371	H. Sakuyama, K. Watanabe	(MEIS)	REFID=12647
BHAT	82	PR D25 2820	P.N. Bhat <i>et al.</i>	(TATA)	REFID=12622
KINOSHITA	82	PRL 48 77	K. Kinoshita, P.B. Price, D. Fryberger	(UCB+)	REFID=12388

MARINI	82	PR D26 1777	A. Marini <i>et al.</i>	(FRAS, LBL, NWES, STAN+)	REFID=12625
SMITH	82B	NP B206 333	P.F. Smith <i>et al.</i>	(RAL)	REFID=12627
KINOSHITA	81B	PR D24 1707	K. Kinoshita, P.B. Price	(UCB)	REFID=12394
LOSECCO	81	PL 102B 209	J.M. LoSecco <i>et al.</i>	(MICH, PENN, BNL)	REFID=10605
ULLMAN	81	PRL 47 289	J.D. Ullman	(LEHM, BNL)	REFID=12395
YOCK	81	PR D23 1207	P.C.M. Yock	(AUCK)	REFID=12617
BARTEL	80	ZPHY C6 295	W. Bartel <i>et al.</i>	(JADE Collab.)	REFID=12158
BUSSIÈRE	80	NP B174 1	A. Bussiere <i>et al.</i>	(BGNA, SACL, LAPP)	REFID=10599
YOCK	80	PR D22 61	P.C.M. Yock	(AUCK)	REFID=12611
ARMITAGE	79	NP B150 87	J.C.M. Armitage <i>et al.</i>	(CERN, DARE, FOM+)	REFID=10593
BOZZOLI	79	NP B159 363	W. Bozzoli <i>et al.</i>	(BGNA, LAPP, SACL+)	REFID=12240
GOODMAN	79	PR D19 2572	J.A. Goodman <i>et al.</i>	(UMD)	REFID=12606
SMITH	79	NP B149 525	P.F. Smith, J.R.J. Bennett	(RHEL)	REFID=12607
BHAT	78	PRAM 10 115	P.N. Bhat, P.V. Ramana Murthy	(TATA)	REFID=12591
CARROLL	78	PRL 41 777	A.S. Carroll <i>et al.</i>	(BNL, PRIN)	REFID=12592
CUTTS	78	PRL 41 363	D. Cutts <i>et al.</i>	(BROW, FNAL, ILL, BARI+)	REFID=12593
VIDAL	78	PL 77B 344	R.A. Vidal <i>et al.</i>	(COLU, FNAL, STON+)	REFID=12599
ALEKSEEV	76	SJNP 22 531	G.D. Alekseev <i>et al.</i>	(JINR)	REFID=12576
		Translated from YAF 22 1021.			
ALEKSEEV	76B	SJNP 23 633	G.D. Alekseev <i>et al.</i>	(JINR)	REFID=12577
		Translated from YAF 23 1190.			
BALDIN	76	SJNP 22 264	B.Y. Baldin <i>et al.</i>	(JINR)	REFID=12260
		Translated from YAF 22 512.			
BRIATORE	76	NC 31A 553	L. Briatore <i>et al.</i>	(LCGT, FRAS, FREIB)	REFID=12261
GUSTAFSON	76	PRL 37 474	H.R. Gustafson <i>et al.</i>	(MICH)	REFID=12580
ALBROW	75	NP B97 189	M.G. Albrow <i>et al.</i>	(CERN, DARE, FOM+)	REFID=12263
FRANKEL	75	PR D12 2561	S. Frankel <i>et al.</i>	(PENN, FNAL)	REFID=12572
JOVANOVIĆ	75	PL 56B 105	J.V. Jovanovich <i>et al.</i>	(MANI, AACH, CERN+)	REFID=12266
YOCK	75	NP B86 216	P.C.M. Yock	(AUCK, SLAC)	REFID=12575
APPEL	74	PRL 32 428	J.A. Appel <i>et al.</i>	(COLU, FNAL)	REFID=12567
FRANKEL	74	PR D9 1932	S. Frankel <i>et al.</i>	(PENN, FNAL)	REFID=12568
YOCK	74	NP B76 175	P.C.M. Yock	(AUCK)	REFID=12569
ALPER	73	PL 46B 265	B. Alper <i>et al.</i>	(CERN, LIVP, LUND, BOHR+)	REFID=12272
LEIPUNER	73	PRL 31 1226	L.B. Leipuner <i>et al.</i>	(BNL, YALE)	REFID=12275
DARDO	72	NC 9A 319	M. Dardo <i>et al.</i>	(TORI)	REFID=12281
TONWAR	72	JP A5 569	S.C. Tonwar, S. Naranan, B.V. Sreekantan	(TATA)	REFID=12283
ANTIPOV	71B	NP B31 235	Y.M. Antipov <i>et al.</i>	(SERP)	REFID=12561
ANTIPOV	71C	PL 34B 164	Y.M. Antipov <i>et al.</i>	(SERP)	REFID=12560
BINON	69	PL 30B 510	F.G. Binon <i>et al.</i>	(SERP)	REFID=12559
BJORNBOE	68	NC B53 241	J. Bjornboe <i>et al.</i>	(BOHR, TATA, BERN+)	REFID=12303
JONES	67	PR 164 1584	L.W. Jones	(MICH, WISC, LBL, UCLA, MINN+)	REFID=12557
DORFAN	65	PRL 14 999	D.E. Dorfman <i>et al.</i>	(COLU)	REFID=12330

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